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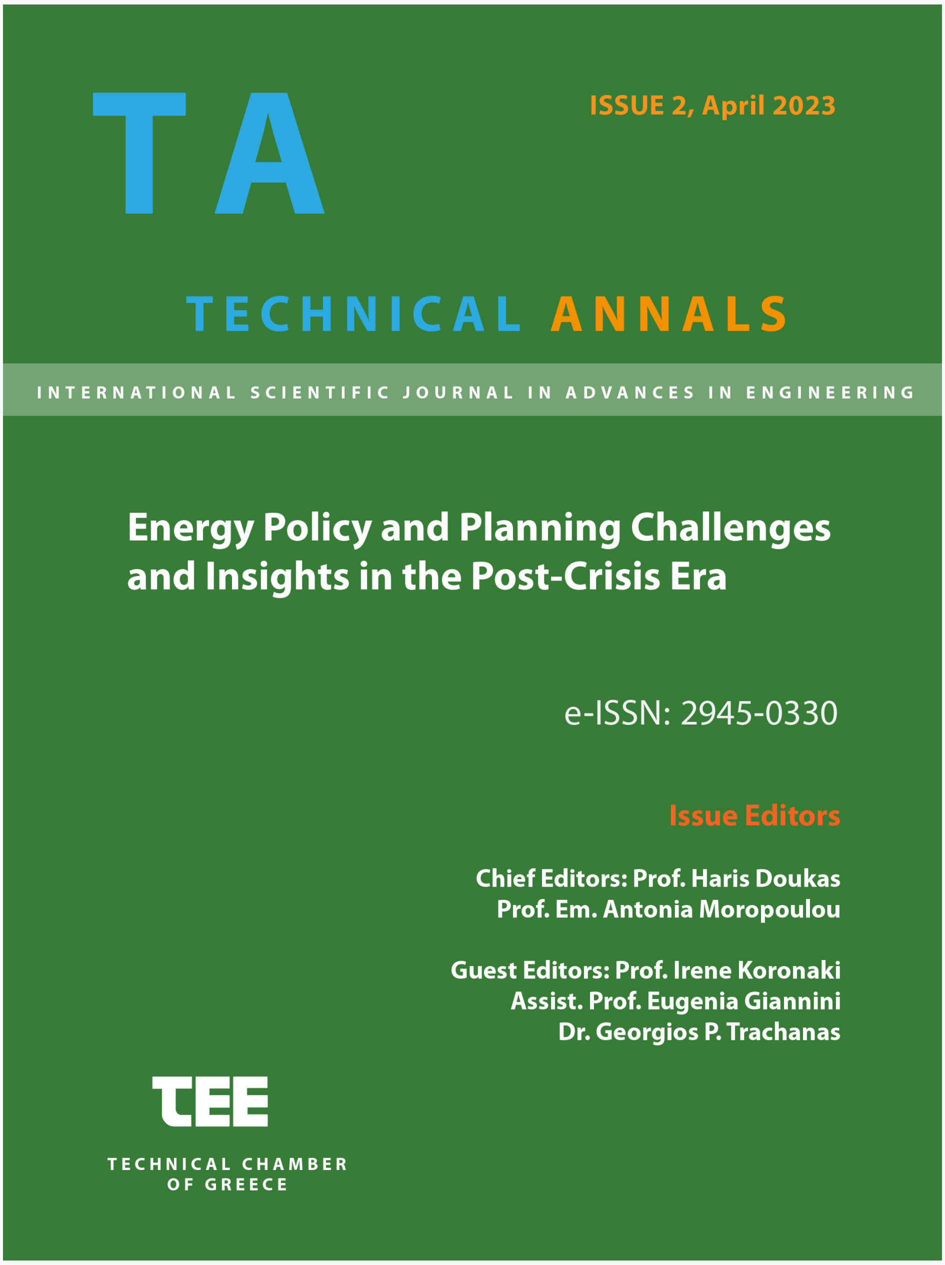

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TECHNICAL ANNALS

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Energy Policy and Planning Challenges and Insights in the Post-Crisis Era

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About

With particular joy, respect and commitment to the history of TEE (TCG), to the future of the scientific role of the Chamber and to the work of Greek Engineers as a whole, the Technical Chamber of Greece is proceeding with the publication of an international scientific journal. After several years without regular scientific publications, due to the special economic situation of the country, but having as a source of our history the TECHNICAL ANNALS, published by the TCG for decades, we undertake this role again to give another scientific podium to the Engineering community.

More specific, the Governing Committee of TCG, in accordance to Decisions No A14/Σ39/2021, A16/Σ7/2022 and A41/Σ16/2022, proceeded to publish of the Scientific Journal entitled «Technical Annals» by the Technical Chamber of Greece (TCG) concerned with Advances in Engineering, in English language. The content of the journal will be available electronically and via Open Access, through the e-Publishing service of the National Documentation Centre (EKT).

The Governing Committee of the TCG assigned the responsibility of the publication to the Editorial Board and the Scientific Board of the Journal.

We inform all Engineers IN Greece and in the World, the Academic and Research Community that we are proceeding with this publication in order to give the floor for communication, publicity and recognition, by the International Community, of the Research and Innovation that Engineers produce in practice, on construction sites,in urban space, in regional areas, in industry, in development, in environment, in energy, in the digital world, in universities, in research centers, in startups, in businesses, etc.

We aspire to attract your interest, find in you critical readers, feed your scientific work and publish the results of your research through the International Scientific Journal of TCG.

Looking forward to an important publication that we'd like to become everyone's business.

Topics

The scope of the journal will include all Fields of Engineering:

1. Civil Engineering
2. Architectural Engineering
3. Mechanical Engineering
4. Electrical & Computer Engineering
5. Rural & Surveying Engineering
6. Chemical Engineering
7. Mining & Metallurgical Engineering
8. Naval Architecture & Marine Engineering
9. Electronic Engineering
10. Engineering of Urban Planning & Regional Development
11. Environmental Engineering
12. Mineral Resources Engineering
13. Production & Management Engineering

Furthermore, it will be concerned with Interdisciplinary Thematic Areas, which are at the cutting edge of Research and Innovation, such as:

Agricultural Engineering and Food Processing, Artificial Intelligence, Aerodynamics, Bioengineering, Circular Economy, Climate Change, Cultural Heritage, Education and Learning Processes, Energy, Environment, Economy, Geoinformatics, Human Modelling, Industrial Symbiosis, Management and Quality Control, Material Science and Engineering, Naval Coastal and Maritime Design Engineering and

Planning, Spatial Planning, Sustainable Development, Systems' and Processes Engineering, Technology, Transportation, Processes, among others, and the thematic areas will be dynamically adjusted and determined taking into account both the progress of Science and Engineering, as well as future trends and the trending concerns and needs of Society.

Information for Volume Editors and Authors

Moreover, conferences, in which TCG is either co-organizing or participating in their Organizing and Scientific Committee, will be able to submit a request to publish their Proceedings (in either Greek or English language) always through the "e-Publishing" mechanism, as long as the request has been submitted to TCG and has the approval of TCG's Governing Bodies, either six months before the conference date *(in cases where the proceedings are to be published prior to the conference initiation)*, or three months before the conference date *(in cases where the proceedings are to be issued after the Conference)*.

The Governing Committee of the TCG assigned the responsibility of the publication to the Editorial Board and the Scientific Board of the Journal; the list of members of each board is herein attached.

Haris Doukas · Antonia Moropoulou · Irene Koronaki · Eugenia Giannini · Georgios P. Trachanas

ISSUE

Energy Policy and Planning Challenges and Insights in the Post-Crisis Era

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The Technical Chamber of Greece (TCG) decided to republish in English a Scientific International Open Access e-Journal. The "Technical Annals" - a journal which was counting decades of life following T.C.G. activities – will be edited by the T.C.G. through e-Publishing Platform at the EKT (National Documentation Centre) and will concern all the advancements in Engineering, ρeferring to the disciplines:

- Civil Engineering
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- Mechanical Engineering
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- Rural & Surveying Engineering
- Chemical Engineering
- Mining & Metallurgical Engineering
- Naval Architecture & Marine Engineering
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- Environmental Engineering
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- Production & Management Engineering

Referring also to interdisciplinary Thematic Areas at the forefront of Research and Innovation such as: Agricultural Engineering and Food Processing, Artificial Intelligence, Aerodynamics, Bioengineering, Circular Economy, Climate Change, Cultural Heritage, Education and Learning Processes, Energy, Environment, Economy, Geoinformatics, Human Modelling, Industrial Symbiosis, Management and Quality Control, Material Science and Engineering, Naval Coastal and Maritime Design Engineering and Planning, Spatial Planning, Sustainable Development, Systems' and Processes Engineering, Technology, Transportation, Processes, et al as dynamically will be defined by the progress of science and engineering, the future trends and the social needs.

Through the e-journal, TCG is aiming to publish at least three volumes per year, to connect Greek Engineers with the International Community of Engineering Science and Innovation, for the benefit of the public interest and the promotion of science through research, innovation, and development, in compliance with its constitutional targets.

Technical Annals is a peer-reviewed journal.

Preface

In the wake of the global Covid-19 pandemic and the ensuing energy crises, the world finds itself at a critical juncture in energy policy and planning. The unprecedented disruptions caused by these events have underscored the urgent need for a reevaluation of energy systems and a comprehensive reassessment of the challenges and opportunities that lie ahead. As we navigate through this new era, it becomes increasingly clear that a paradigm shift in energy policy and planning is imperative to ensure a sustainable and resilient energy future.

In this new era, energy policy and planning must confront a multitude of complex and interconnected challenges. The transition to a low-carbon economy requires the further deployment of renewable energy technologies, alongside the integration of energy storage and smart grid systems. Additionally, the need for increased energy efficiency, the decarbonisation of traditional fossil fuel-based industries, and the electrification of transportation and other industrial processes demand a holistic approach that considers infrastructure requirements, regulatory frameworks, and public acceptance. These challenges necessitate a multidisciplinary and collaborative approach, engaging stakeholders from academia, industry, government, and civil society.

In this special issue, we aim to explore these energy policy and planning challenges and insights in this new era. By analysing case studies, policy frameworks, and emerging trends, some valuable insights are provided which may guide decision makers and stakeholders in formulating effective strategies for the long-term sustainability and resilience of energy systems.

In total, 27 papers were submitted in the framework of the present special issue; 14 of which came from the 2nd International Conference entitled “Transdisciplinary Multi-spectral Modeling and Cooperation for the Preservation of Cultural Heritage: Recap-turing the World in Crisis through Culture” and addressed energy topics that interface with cultural heritage. A double-blind peer review process was followed and, after consequent revision, where each paper received two to three review reports, 13 papers were accepted for publication (48% acceptance rate). The accepted papers were published in this issue of the Technical Annals journal.

The present exploration of energy policy and planning insights has shed light on several key topics including sustainability, electrification in transportation, smart grids, environmental, social, and governance (ESG) considerations, the climate policy debate, as well as the cultural heritage aspects of energy. The challenges we face are immense, but they also present an opportunity for the scientific community to formulate inclusive frameworks, models and systems towards a more sustainable, resilient, and equitable energy system.

The key outcomes of the present special issue can be summarized as follows:

- Electrification in transportation has emerged as a transformative solution to reduce carbon emissions and dependence on fossil fuels. To accelerate the adoption of electric vehicles, the development of robust charging infrastructure, supportive policies, and financial incentives are of high importance. Additionally, smart grids have the potential to revolutionize energy management and enhance grid resilience. Therefore, the integration of energy storage systems with renewable energy sources and smart grids can enhance grid stability, optimize energy use, and facilitate the shift towards a more decentralized and sustainable energy system.
- ESG considerations have become increasingly important in energy policy and planning. Policy makers and industry leaders must prioritize ESG criteria in decision making processes towards fostering transparency, accountability, and stakeholder engagement. By establishing a standardised and normalised ESG materiality framework may help companies identify sustainability issues that are most relevant to their industry and context, and develop strategies to address them effectively.

- By integrating climate resilience into energy policy and planning, we can reduce vulnerability and minimize potential losses. In this direction, the concept of Loss and Damage underscores the importance of proactive risk management and disaster preparedness. International climate finance mechanisms should be strengthened to ensure that adequate resources are available to support vulnerable countries in their energy transition and resilience-building efforts.
- Finally, the special issue has highlighted the cultural heritage aspects of energy and the need to consider the social and cultural dimensions in energy policy and planning. Thus, recognizing the diverse cultural values attached to energy resources and infrastructure is crucial for fostering social acceptance and minimizing conflicts. In this context, preservation of cultural heritage, community engagement, and inclusive decision making processes should be integral parts of energy projects and policies.

The present edition would not have been possible without the commitment of the editors of this special issue (Antonia Moropoulou, Haris Doukas, Irene Koronaki, Eugenia Giannini and Georgios Trachanas), as well as the valuable assistance of the editing team at Technical Annals (Fotini Kyritsi, Evridiki Karathanasi, Panagiotis Vrelos, Maria Sinigalia, Manolis Erotokritos, Isabella Tsavari, Dimitris Psarris), to whom we express our most gratitude.

April 2023 Haris Doukas – Antonia Moropoulou

Issue Contents

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Application of energy signature method to analyze the energy consumption patterns before and during the COVID-19 pandemic in two public office buildings in Thessaloniki, Greece

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Abstract. The global COVID-19 pandemic had a significant impact on building energy use as a result of local emergency policies such as lockdowns, remote working and increased building ventilation being applied for an extended time. In this study we apply the energy signature method to two public office buildings in Thessaloniki, Greece to compare their energy performance before (2018-2019) and during (2020-2021) the pandemic. The energy signature method normalizes electricity and natural gas consumptions to the average climate, eliminating the influence of annual weather patterns on energy use and differentiates between heating, cooling and base energy. This allows us to compare the two periods using data from monthly utility bills. Results show a reduction (ranging from 16% to 26%) in both heating and cooling energy consumptions during the pandemic period for both buildings which is not related to differences in annual weather patterns. Although this old method is quick and straightforward to use it has its own limitations which are discussed along with potential ways it can improve.

Keywords: Building Energy, Energy signature, COVID-19, Consumption, Pandemic

1 Introduction

Building energy performance is affected by several parameters, such as the local climate, the thermophysical properties of its envelope, HVAC and lighting equipment and occupant behavior. The COVID-19 Pandemic disrupted normal building use globally, as lockdowns, travel restrictions and remote workingmeasures were implemented to reduce transmission of the SARS-COV 2 virus. Additionally, local governing bodies issued special guidelines for increased natural and mechanical ventilation to lower indoor viral concentration levels.

In Greece, the Ministry of Health, following REVHA and GHI-net recommendations, issued technical guidance for the operation and maintenance of HVAC systems [13] mainly suggesting prolonged operation of ventilation systems, use of air filters, use of natural ventilation and prevention of air recirculation. These changes in building operation and occupancy were widely applied in tertiary sector and especially public buildings, altering the “conventional” energy use patterns.

The aim of our study is to contribute to the increasing body of literature that studies the impact of the COVID-19 pandemic on building energy use. We compare the energy consumption of two public buildings in Thessaloniki, Greece between a pre-COVID-19 period (2018-2019) and a COVID-19 period (2020 – 2021). To perform such comparison, we utilize the energy signature method which allows us to adjust monthly energy consumptions to the local climate, thus removing the influence of annual weather patterns. Findings indicate a decrease (ranging from 16% to 26%) in annual heating and cooling demand during the pandemic in both buildings which is not attributed to changes in annual weather.

2 Background

The COVID-19 pandemic had a complex influence on building energy use [16]. While some operational changes, such as reduced occupancy, have led to a decrease in energy consumption for heating, cooling and lighting, others, such as increased need for natural or mechanical ventilation have led to an increase. Kang et al.[10] studied the impact of COVID-19 on energy consumption by building use type in South Korea by relating electricity and natural gas energy data with regional COVID-19 big data. The study showed average electricity usage decrease in office buildings up to 5% and monthly gas decrease up to 8.37% in various regions in comparison with electricity consumption increase in residential buildings. A similar studyby Madurai Elavarasan et al. [12] highlighted the decrease in electricity demand during the pandemic in the commercial and industrial sector in comparison to the increase in the residential sector due to new lifestyle of staying and working from home.

Additionally, various studies have shown the huge impact of HVAC irregular operation on the energy consumption of buildings. Extended HVAC operation schedules, while being crucial for a healthy indoor environment, significantly increase the energy consumption. Similarly, introducing higher air flow rates in the space results in much higher energy consumption as the systems operate constantly on their full capacity. A study by Mokhtari and Jahangir [14]showed that when HVAC operation hours were almost doubled, the energy consumption increased by up to 39.2%.

Another study by Escrivà-Escrivà et al.[6]showed that even one extra hour of HVAC operation after occupancy could lead up to 4,48% increase in energy consumption. Zheng et al[22] investigated the impact of applying the HVAC operational recommendations during the pandemic (such as introducing 100% air volume and no recirculation) on the energy consumption. By using Chinese public building energy consumption historical data, they estimated an increase of up to 128%. These findings indicate that there is no simple answer regarding the influence of the COVID-19 pandemic on tertiary building energy use.

In our study we study this influence by applying the energy signature method to two tertiary sector public buildings. Energy consumption in buildings can be estimated by either analytical simulation models using thermodynamic equations or data-driven static or dynamic models based on data collection [2, 19, 21]. The energy signature method belongs to the latter.

Static models, such as Ordinary Least Squares (OLS) linear regression method used in this study, are suitable for energy prediction demand over long time intervals such as months [20].These methods are usually applied when accuracy is not a high priority, as they do not analyzeenergy use patterns at finer temporal scales. They are commonly applied in Measurement and Verification processes together with on-site inspections for proposing energy retrofit measures as described in IPMVP protocols [8].

The past years there is a rise in dynamic models which are made possible through smart metering and recent advances in Machine Learning (ML) [17].These modelscan be trainedon weekly, daily, or hourly weather profiles and are constantly updated on newly available data. Hence, they are suited for both long-term and short-term forecasting of energy use with good accuracy. However, a limitation of such models is the requirement for real time big data which is only possible with the use of smart meters [18].

The energy signature method has been used extensively for decades with its roots found in the 1950's [9]. Despite its relative simplicity it is used even today in several building and urban energy studies[1, 4, 5, 15].The method relies on establishing a correlation function (linear, polynomial etc.) between energy consumption and one or more parameters that significantly influence the consumption patterns, such as outdoor air temperature, building operating conditions, etc. The method is suitable for application in tertiary sector buildings. This is because parameters such lighting and HVAC equipment, as well as occupant behavior is considered stable and can be directly related to energy signatures [11].

3 Methodology

Our goal is to compare the energy consumption patterns two years before the COVID-19 pandemic (2018-2019) and during the pandemic (2020-2021) in two case-study public buildings in Thessaloniki, Greece. Weather has a significant influence on energy consumption for heating, cooling and ventilation. Comparing consumption patterns to detect possible differences due to changes in building use we need to eliminate the influence of weather on energy use data. This is achieved with the energy signature method that normalizes energy consumption to the "average" conditions of the local climate.

Normalized energy consumptions can then be directly compared to detect any changes between the pre-pandemic and pandemic periods that could be attributed to changes in building use, due to emergency policies such as lockdowns. An additional advantage of the method is that it also allows us to differentiate between heating, cooling and base loads by relating energy use with air temperatures.

The energy signature method we employed in this study is described in the BS EN 15603:2008 standard [7]. ASHRAE calls this method "base model" in the Guideline on "Measurement of Energy and Demand Savings" [3]. Since energy use is recorded for any building in monthly utility bills, it can be easily related with outdoor air temperature data, as long as the building:

1. maintains a constant internal temperature through appropriate devices (thermostats, etc.),
2. has stable internal gains and
3. has low or zero solar gains from passive systems.

We applied the energy signature method to two buildings in Thessaloniki, Greece (Fig.1): The first (Building A) is the ex-town hall of the Municipality of Triandria, a four-story building erected in 1977 with a total floorspace of 1018m², of which 826m² are conditioned. It has a poor energy performance, ("E" class energy certificate) with no insulation and single-pane windows. It is heated with a central gas boiler and cooled with old air conditioning split units. The ground floor is a Citizen Service Center, the first and second floors are offices and the third is a conference hall. The building has operable windows for natural ventilation.

The second (Building B) is a six-story building erected in 2006, with a total floorspace of 1998m², of which 1574m² are conditioned. It has mediocre energy performance ("C" class energy certificate) as its envelope construction characteristics comply with the Greek Insulation Code that preceded the current Building Energy Code (KEnAK). It is heated and cooled with a central VRF unit, although some auxiliary spaces that were later converted to office space are independently heated and cooled with split units and electric radiators. Apart from offices it houses a "social pharmacy" and medical examination services. The building has operable windows for natural ventilation. Personal communication with the building's manager revealed that HVAC operation program was not changed during the pandemic.

Fig. 1. The two case-study buildings. Left: Building A. Right: Building B.

We acquired utility bills for the 2018 – 2021 period from the Municipality of Thessaloniki and monthly air temperatures for the 2011 – 2021 period from the National

Meteorological Service. We then applied the energy signature method using Ordinary Least Squares (OLS) linear regression, relating mean energy consumption (electricity and/or natural gas) to mean outdoor air temperature. Each examined year was divided into a heating and a cooling period and regressions were performed for each building, fuel, year and cooling / heating period (Figs. 2 – 4) Afterwards we verified their goodness of fit by calculating R^2 (Figs. 2 – 4) and the Coefficient of Variation of the Root Mean Square Error CV(RMSE) (Tables 2 and 3).

Using the OLS regression parameters, we then estimate the normalized monthly energy consumptions for the climate of Thessaloniki, as it is described by the mean monthly air temperatures (2011 – 2021) of the last decade (Table 1). From the regressions we can calculate a balance temperature where the heating and cooling regression lines intersect. This is the theoretical outdoor air temperature where the building is "free running" and is useful in identifying the month with the least energy use for heating and cooling. We assume that the electricity consumption of this month corresponds to the minimum "base" consumption for the year (i.e. lighting, equipment, appliances, elevators etc).

Table 1. Monthly mean average temperatures for the four examined years (2018 – 2021) and the last decade (2011 – 2021). The Mean Absolute Percentage Error (MAPE) is also given for each year, calculated against the 2011 – 2021 period. Lines indicate the distinction between heating and cooling periods.

month	2018	2019	2020	2021	2011-2021
Jan	7.6	4.9	7.0	8.5	6.8
Feb	8.9	8.0	9.3	8.9	9.1
Mar	11.8	11.9	10.8	9.7	11.2
Apr	17.4	14.5	13.1	13.0	14.9
May	21.6	19.3	19.1	20.0	20.2
Jun	24.2	25.8	23.5	23.9	24.5
Jul	26.4	26.9	26.6	28.1	27.0
Aug	26.8	27.8	26.4	28.4	27.3
Sep	23.3	23.7	24.5	22.5	23.1
Oct	18.1	19.0	19.1	15.4	17.4
Nov	13.1	16.0	13.1	13.3	13.4
Dec	7.1	9.8	11.1	8.2	8.6
MAPE	6%	9%	6%	7%	-

For the present climate of Thessaloniki there is a clear separation between a heating and a cooling period, since months with neutral temperatures, such as May and October exist (mean air temperature around 19 – 20°C). Using the balance temperature, we then differentiated between monthly heating and cooling energy, after subtracting the base consumption from the estimated total. Finally, we calculated the average base, heating and cooling consumptions for the pre-pandemic and pandemic periods for each of the two buildings and compared results.

4 Results

Results from the application of the energy signature method in the two buildings are presented in Figs. 2 – 6 and Tables 2 – 3. Regarding the goodness of fit we observe that R^2 can vary significantly from very low (0.04) to very high (0.97). Some of the lowest R^2 values are observed in electric energy use for building A (all years) and only for year 2021 for building B. Gas consumptions for building A have relatively good R^2 values, ranging from 0.64 to 0.81. It is interesting to note that except for 2021 electricity consumption for building B has a very strong linear trend, with R^2 ranging from 0.87 to 0.97. However, calculated CV(RMSE)s (Tables 2 and 3) show that the linear models have a low percentage error for electricity use (6% - 22%) and a mid to high percentage error for heating use (2% - 41%).

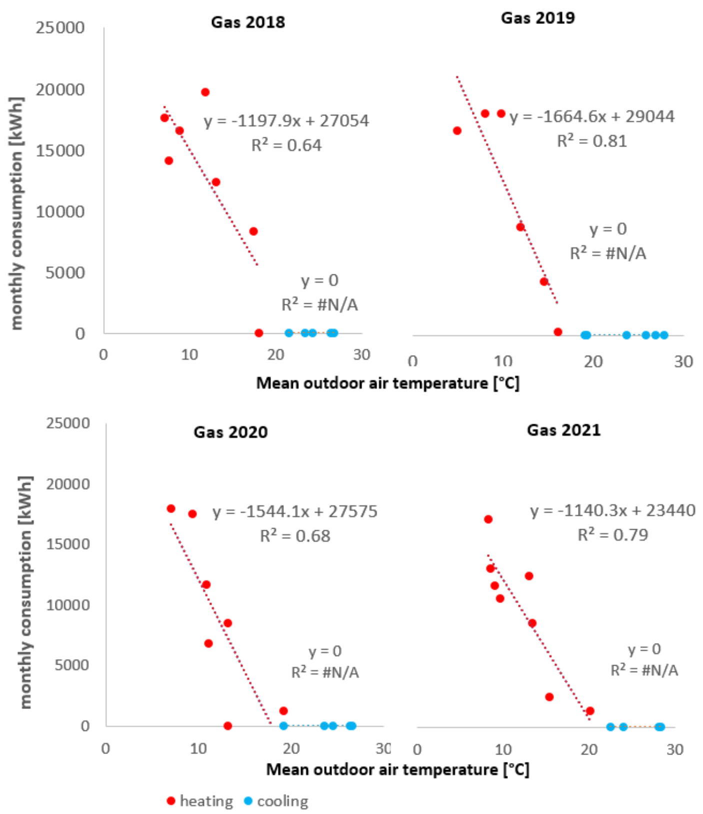

Fig. 2. OLS regressions for Building A (Natural gas energy consumption)

These metrics can be explained as follows: The combination of high R^2 and low CV(RMSE) in some cases of electricity use reveals that the linear model is introducing a large bias which in these cases fails to capture sufficiently the variability of the underlying data. However, it is still able to make reasonably accurate predictions, as indicated by the good CV (RMSE). The combination of relatively high R^2 values with mediocre CV(RMSE) in the case of natural gas use shows that the model is explaining a good proportion of data variance, but it is less accurate.

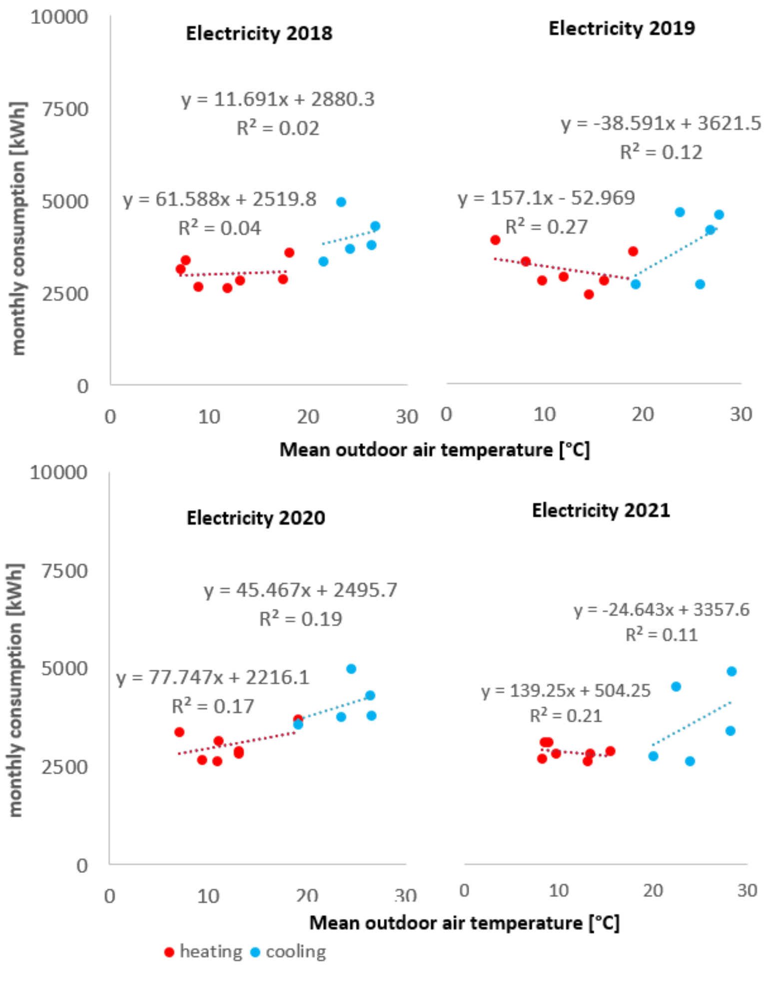

Fig. 3. OLS regressions for Building A (electricity energy consumption).

We also observe that there are differences between actual and normalized energy consumptions in both buildings, but values tend to be close (Tables 2 and 3). This can be attributed to the fact that the monthly air temperatures of the four examined years are –more or less– similar to the 10-year averages, with 2019 being the year with the highest declination (9%) from the climatic norm (Table 1).

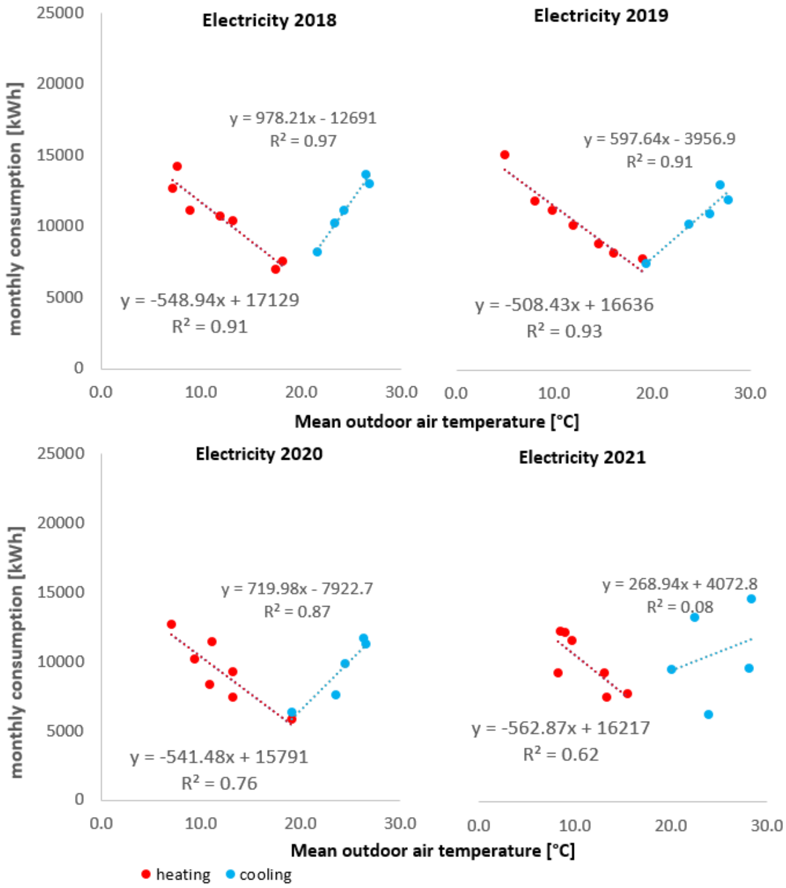

Fig. 4. OLS regressions for Building B (electricity energy consumption).

Figs. 5 and 6 demonstrate the observed differences in normalized monthly energy consumptions for the pre-COVID-19 and COVID-19 period and for the two buildings. Building A, having a poorly insulated envelope and an outdated gas boiler consumes a lot of energy for heating. During the COVID-19 period we observe a reduction of 16% and 22% for heating and cooling respectively that is not attributed to annual differences in weather. Base loads remain unchanged between the two periods. Building B has more than twice the base loads of Building A, as it is a much larger building with more equipment, including some medical devices. For Building B energy consumptions for heating and cooling are roughly equal. As with Building A, Building B demonstrates a reduction in energy consumption during the COVID-19 period for both heating and cooling by 26% and 22% respectively, while a negligible reduction of 1% in base consumption is also observed.

Table 2. Regression results for building A.

	actual consumption [MWh]		normalized consumption [MWh]		CV (RMSE) [%]	
	n.gas	elec.	n.gas	elec.	n.gas	elec.
2018	90.0	41.3	94.5	41.0	31%	12%
2019	66.0	41.2	67.6	41.3	35%	17%
2020	66.0	41.7	68.8	43.1	41%	11%
2021	77.8	41.2	72.9	41.3	28%	12%

Table 3. Regression results for building B.

	actual consumption [MWh]		normalized consumption [MWh]		CV (RMSE) [%]	
	n.gas	elec.	n.gas	elec.	n.gas	elec.
2018	-	130.0	-	131.2	-	6%
2019	-	128.1	-	128.2	-	5%
2020	-	112.1	-	114.7	-	11%
2021	-	117.4	-	123.5	-	22%

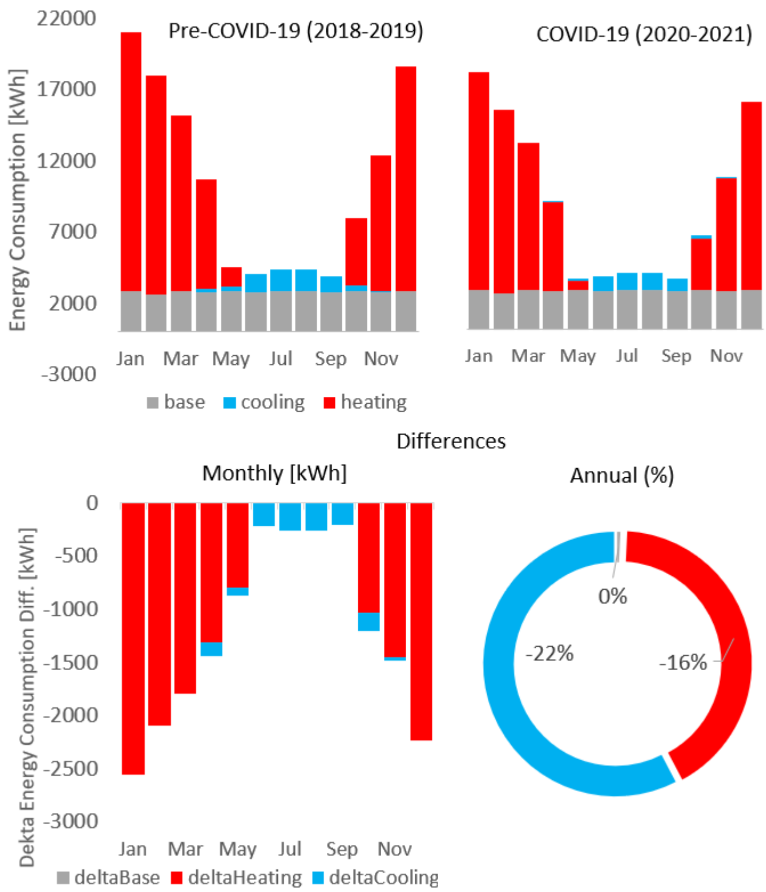

Fig. 5. Normalized average monthly energy consumptions in the pre-COVID-19 (2018-2019) and COVID-19 (2020-2021) periods.

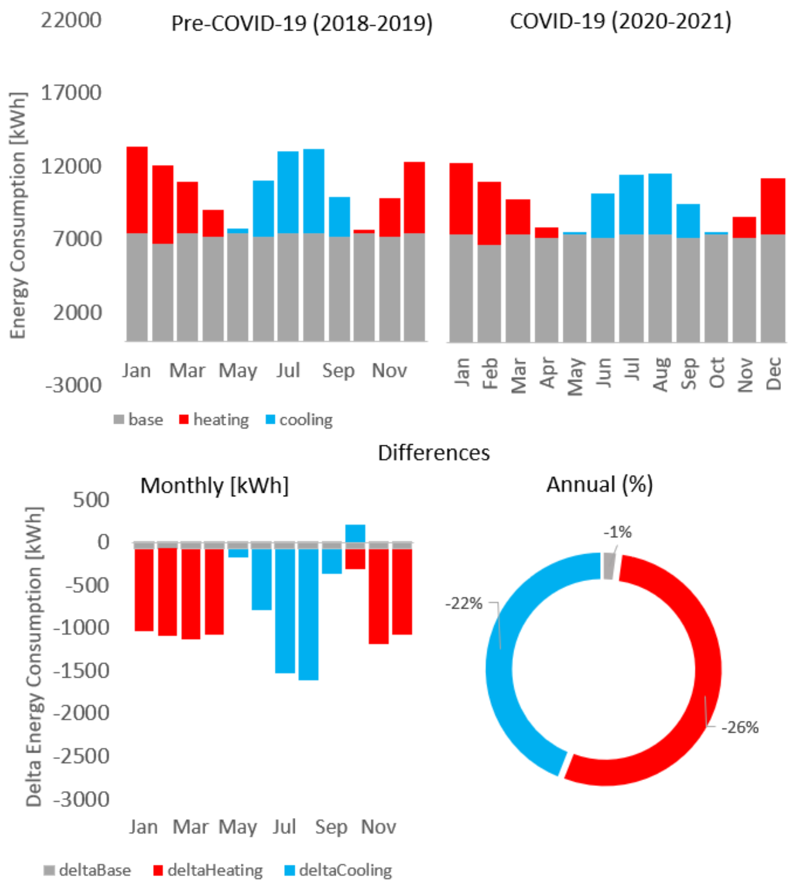

Fig. 6. Normalized average monthly energy consumptions in the pre-COVID-19 (2018-2019) and COVID-19 (2020-2021) periods.

5 Discussion

The application of the energy signature methods for two-year periods before and during the COVID-19 pandemic revealed a significant reduction in energy consumption for both heating and cooling, ranging from 16% to 26% that is not attributed to changes in annual weather patterns. Base energy use for lighting and other equipment and appliances remained virtually unchanged in both buildings. Theoretically, base consumptions should be lower too, as building occupancy is reduced. The method presented here, is not able to differentiate base consumption between its components (e.g. lighting, equipment, elevators etc.) without on-site building inspections or without making several assumptions about building use.

While we demonstrated that the energy signature method is a valuable tool for interpreting and comparing building energy consumption using nothing else but utility bills, we also acknowledge its limitations. We apply the simplest method, the OLS linear regression, which can explain only a fraction of energy use variance, especially regarding electricity. Our main data source is utility bills which allows for a monthly step of calculations. This keeps the method simple but fails to provide interpretations of building energy use in finer temporal scales (e.g. a typical winter or summer day). Another limitation is that we can only assume that the observed reductions in energy consumption are attributed to COVID-19 pandemic and not to some other factor (e.g.unrelated changes to occupant behavior and/or building use). These limitations can be improved by:

Applying more sophisticated regression methods such as polynomial regression or ML algorithms such as Random Forests, Gradient Boosting and Neural Networks. ML, however, requires big data which cannot be extracted from simple utility bills.

Measuring energy consumption at finer temporal scales, using IoT smart meters and indoor climate sensors. Constant real-time monitoring of energy use and indoorenvironmental conditions requires a significant investment in IoT equipment and adds an additional layer of complexity to all calculations.

Conducting an on-site building inspection to record heating/cooling setpoints and create an energy inventory, from where base consumptions can be broken down to specifics (e.g. lighting, equipment, appliances etc). Inspections could also diagnose problems with HVAC equipment and operation.

Using daily energy use and occupant behavior profiles. Big data gathered from buildings of similar type and in the same climate could be used to infer energy consumption at finer temporal scales from monthly utility bills.

The relevant literature (see Background section) mentions both increases and decreases of energy consumptions during COVID-19 pandemic. The significant decrease in energy consumption observed in both buildings can be attributed to their sparser use during the pandemic, but we cannot verify to what extend the recommendations for increased mechanical and natural ventilation were followed or not using the energy signature method alone.

6 Conclusions

We utilized the energy signature method to compare energy consumptions of two public office buildings before and during the COVID-19 pandemic. We found that the energy consumption during the pandemic period was reduced in both case studies. In building A, which utilizes natural gas for central heating and electricity for local cooling, the total energy consumption for heating was reduced by 22%, while for cooling by 16%. Similar energy decrease of 22% for heating and of 26% for cooling was found in Building B which utilizes only electricity. The energy signature method is quick and easy to use, hailing back to a pre-digital era. Despite its limitations we believe that it can still be a useful analysis tool when combined with on-site inspections and more rigorous methods of data collection.

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Exploring the energy community actions to alleviate energy poverty in the Greek context

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Abstract. Energy poverty is a significant problem in Greece, affecting many people and exacerbating social inequality. Lack of access to affordable and reliable energy negatively impacts health, comfort, and economic opportunities. While various initiatives have been implemented to address energy poverty, energy communities are emerging as a promising approach to tackle this issue. Energy communities refer to groups of people who come together to produce, consume, and manage their energy resources collectively. They enable households and communities to reduce their energy bills, improve living conditions, and enhance social and economic resilience. Energy communities can also stimulate local development and promote renewable energy technologies, contributing to a more sustainable and equitable energy system. This paper reviews energy poverty alleviation actions by energy community initiatives across Europe and proposes relevant energy poverty alleviation actions for energy communities in Greece, aiming to contribute to the ongoing debate on how energy communities can alleviate energy poverty.

Keywords: energy poverty, energy communities, collective actions.

1 Introduction

In Greece, a considerable number of people experience energy poverty, which contributes to social inequality. Lack of access to affordable and dependable energy services has adverse effects on people's well-being, quality of life, and economic prospects. As a result, the affected communities suffer from long-term consequences. While various initiatives have been implemented to address energy poverty, more attention has been given to the potential of energy communities as an effective approach to tackle this issue. Energy communities refer to groups of people or organizations who come together to produce, consume, and manage their energy resources collectively. They provide a promising avenue for addressing energy poverty by enabling households and communities to reduce their energy bills, improve their living conditions, and enhance their social and economic resilience. Energy communities can also stimulate local development and promote the adoption of renewable energy technologies, contributing to the transition towards a more sustainable and equitable energy system.

This paper aims to investigate the potential of energy communities and the actions they can take to mitigate energy poverty in Greece. Specifically, the paper starts with presenting the Greek institutional context regarding the alleviation of energy poverty and how it relates to social and environmental justice. Next, it delves into the energy democracy and energy justice concepts in the context of energy poverty to shed light on their relevancies. It also presents the Greek legal framework that governs the establishment and operation of energy communities, reviews the energy poverty alleviation actions led by energy community initiatives across Europe, and it presents some of the existing case studies identifying the six main strategic areas that the relevant actions can be enlisted. A short reference on the main challenges in implementing such actions is also presented.

Finally, the main output of this paper is an extensive exploration and documentation of the relevant energy poverty alleviation actions that can be developed by energy communities acting in the Greek legal and societal context. By doing so, this paper seeks to contribute to the ongoing debate of whether energy communities can contribute in mitigating energy poverty and in what way.

2 Energy poverty in the Greek context

2.1 Energy Poverty definition and institutional alleviation efforts in Greece

Energy poverty, recognized by Greek Law 4001/11 as a prominent social issue, refers to the inability of consumers with low income, as evidenced in their tax returns, to meet their needs for energy, i.e., electricity or natural gas due to either their professional and marital status, or special health conditions, and other factors. In Greece, financially weak residential customers affected by energy poverty are classified as Vulnerable Customers. The National Action Plan to Combat Energy Poverty (NEPAP, 2021) defines a household as energy poor based on a multi-dimensional indicator calculated from the adjusted net income of the household, the minimum required energy consumption, and the median income of the corresponding population for all households. The country has two pillars of legislation to address energy poverty, the first being protection of vulnerable social groups through reduced energy consumption prices and benefits for the weakest, and the second being the facilitation of access to energy through self-production, both by private RES units and energy cooperatives.

The Greek National Energy and Climate Plan [43] sets an ambitious target of reducing energy poverty by 50% by 2025 and by 75% by 2030, with 2016 as the reference year. Measures and policies to address energy poverty include the Social Residential Tariff (SRT), the allowance for the purchase of heating oil, and the improvement of energy efficiency of buildings, among others. The National Action Plan to Combat Energy Poverty (NEPAP, 2021), implemented through information sharing and education, consumer protection, and development perspectives, aims to improve the Social Residential Tariff and introduce the "energy card" to enable affected households to consume a certain amount of energy products during exceptional times of crisis. The plan also proposes the energy upgrading and installation of renewable energy systems in the buildings of affected households to promote self-consumption and save energy.

However, the lack of a definition of energy poverty [1], contributes to the difficulty of understanding how to tackle the issue at different policy levels. Energy poverty is a complex social phenomenon, and identifying energy-poor households has been based on welfare criteria and indicators rather than a definition. As a result, some households that suffer from energy poverty episodes are difficult to identify and help.

To tackle energy poverty in Greece, it is crucial to identify the factors and characteristics that make up an energy-poor household and quantitatively analyze the affected households' number and spatial distribution. This information can guide specific and locally oriented incentives for the implementation of planned policy measures. Funding for development and fair sharing among affected persons and amendments to the regulatory framework are essential for achieving the goals of the National Energy and Climate Plan [43] and the National Action Plan to Combat Energy Poverty [44].

Tackling energy poverty in Greece requires a multi-faceted approach that targets improving the energy efficiency of homes and changing of the energy model with the uptake of renewable energy sources through the establishment of energy cooperatives. The implementation of specific and locally oriented incentives and the provision of funding are crucial for achieving the goals of legislation and plans aimed at alleviating energy poverty in Greece.

2.2 Linkage between energy poverty and social and environmental justice

Energy poverty is not just an economic issue, but it also intersects with social and environmental justice concerns. Low-income households are more likely to live in poorly insulated homes, which leads to higher energy bills, more greenhouse gas emissions, and poorer air quality [23]. Moreover, the effects of energy poverty disproportionately affect certain social groups, such as the elderly, disabled, and families with young children [11].

Addressing energy poverty can therefore contribute to broader social and environmental justice goals. By improving the energy efficiency of homes and promoting the use of renewable energy sources, not only can energy bills be reduced for low-income households, but also greenhouse gas emissions and air pollution can be decreased, resulting in a healthier environment for all.

Furthermore, promoting access to energy through self-production by energy cooperatives can also lead to a more democratic and participatory energy system, where citizens have a greater say in how their energy is produced and consumed [13]. The linkages between energy poverty and broader social and environmental issues highlight the need for a more holistic approach to energy policy, one that takes into account not only economic concerns but also social and environmental factors.

3 Energy democracy and energy justice in the context of energy poverty

3.1 Defining energy democracy and energy justice

Energy democracy and energy justice are two emerging concepts in the fields of energy policy and environmental justice. Energy democracy refers to the idea that communities should have control over their energy systems and participate in decisions related to energy production, distribution, and consumption [19]. This can involve community ownership of energy infrastructure, cooperative energy models, and participatory decision-making processes. The goal of energy democracy is to create a more decentralized, democratic, and equitable energy system that benefits all members of society.

According to Sovacool and Dworkin [19], energy democracy "refers to a process of democratization of energy production, distribution, and consumption through the greater involvement of communities and individuals in energy decisions and policies." This can take many forms, such as community-owned renewable energy projects, energy cooperatives, and participatory decision-making processes. The goal of energy democracy is to shift the power dynamics of the energy system away from large corporations and towards communities and individuals.

Energy justice, on the other hand, focuses on the equitable distribution of energy resources and services. As defined by Schlosberg et al. [17], energy justice "concerns the fair distribution of the benefits and burdens of energy systems and their impacts on people and the environment." This includes issues such as access to energy services, affordability, and environmental impacts. Energy justice recognizes that certain communities, such as low-income and minority communities, are often disproportionately impacted by energy-related environmental hazards, such as pollution from fossil fuel power plants.

The concepts of energy democracy and energy justice are closely related, as both aim to address the social and environmental injustices associated with the current energy system. By empowering communities to have greater control over their energy systems and ensuring that all members of society have access to sustainable and affordable energy services, these concepts can help to create a more just and equitable energy system.

3.2 Energy democracy and energy justice as necessary elements of the EU energy transition

Energy democracy and energy justice are crucial components of the European Union's (EU) efforts to transition towards a more sustainable and equitable energy system [31], [36], [37]. The EU has set ambitious targets for reducing greenhouse gas emissions, increasing the use of renewable energy, and improving energy efficiency. However, these goals cannot be achieved without the participation and engagement of communities and citizens.

The EU's Clean Energy for All Europeans package [32] emphasizes the importance of empowering consumers and communities to participate in the energy transition and promoting the development of community-owned renewable energy projects, thereby promoting energy democracy. Furthermore, energy justice is a critical component of the EU's Energy Union Strategy, which aims to ensure that all citizens have access to affordable, reliable, and sustainable energy services, while also addressing the environmental impacts of the energy system [32].

By promoting energy democracy and energy justice, the EU can build public support for the energy transition and create a more equitable and sustainable energy system. This can help to address social and environmental injustices associated with the current energy system and ensure that the benefits of the energy transition are shared by all members of society [4].

3.3 Relevancy with community efforts to address energy poverty in Greece

Energy democracy and energy justice can play a crucial role in addressing energy poverty in Greece, which is a significant social and environmental issue. Greece has one of the lowest performances on almost every index of energy poverty in the European Union, indicating that a significant proportion of households unable to afford basic energy services [30].

Energy democracy can empower communities to take control of their energy systems and develop local solutions to energy poverty, such as community-owned renewable energy projects [19]. This can provide households with access to affordable and reliable energy services and reduce their dependence on fossil fuel-based energy sources. One example of energy democracy in action is the establishment of community-owned solar projects in low-income neighborhoods in Athens, which promote local participation and access to affordable renewable energy [19]. An example of energy justice in Greece is the social tariff program, a policy initiative that provides financial support to low-income households for energy bill [38].

Energy justice can also help to address energy poverty by ensuring that all members of society have access to affordable and sustainable energy services [3], [17]. This can be achieved through policies and programs that provide targeted support to low-income households and prioritize the development of renewable energy sources [3].

By promoting energy democracy and energy justice in Greece, policymakers can work towards reducing energy poverty and creating a more equitable and sustainable energy system [7], [10]. This can have important social and environmental benefits, such as improving public health, reducing greenhouse gas emissions, and enhancing energy security [48], [49].

4 Energy communities: a vehicle to energy democracy

4.1 The launch of energy community concept in the Greek legal framework

Energy Cooperatives (EC) in Greece are a new way of self-generation and self-consumption of electricity that allow consumers to become producers and are based on the principles of social and solidarity economy. The term “community” is used instead of “cooperative” and the purpose of each EC can be profitable or not. Members of an EC can be natural persons, legal entities of private and public law, as well as regional and local authorities, with a minimum number of members required. The legislation ensures that each member has equal participation rights in the General Assembly of the EC. Recent amendments to the legislation abolished the priority examination of grouped applications and increased the limit of virtual net metering. However, some issues still exist, such as the legal framework and the resistance of the traditional monopolistic model of electricity generation.

The establishment of EC in Greece is regulated by Law 4513/2018[40], which defines an EC as a civil cooperative of exclusive purpose that aims to promote innovation in the energy sector, tackle energy poverty, and enhance energy self-sufficiency and security. The law specifies that ECs may include actions to support vulnerable consumers and citizens living below the poverty line and undertake social policy initiatives such as energy upgrade of residences or reducing the energy consumption of buildings. The legislation also encourages the participation of regional and local authorities in ECs, which is of great importance for their financial capital to invest in EC and encourage energy autonomy.

In conclusion, ECs in Greece offer a new way of self-generation and self-consumption of electricity, based on the principles of social and solidarity economy. Although some issues still exist, such as the legal framework and the resistance of the traditional monopolistic model of electricity generation, ECs have the potential to enhance energy self-sufficiency and security, tackle energy poverty, and promote innovation in the energy sector.

4.2 The new regulations of Law 5037/2023 for Energy Communities

The latest regulations outlined in Law 5037/2023 [41] address photovoltaics, self-consumption, and Energy Communities, and they aim to align national legislation with EU Directives 2018/2001 and 2019/944. These Directives emphasize the importance of citizen participation in the energy transition, as part of the “Clean Energy for All” European legislative package, which was finalized in 2019. The harmonization of the Directives with national law represents an essential institutional step to involve citizens in the energy transition fully. This move replaces the 2018 Law 4513/2018[40] on energy communities. However, the use of the energy community institution to satisfy energy needs, as was the case with Law 4513/2018[40], presented certain challenges. Therefore, the integration of the two Directives is an opportunity to strengthen the necessary supporting framework for healthy development and further strengthen the role of local societies in the energy transition.

Under the new law, Law 4513/2018’s Energy Communities will be replaced by two new forms of energy cooperatives: Renewable Energy Communities (RECs) and Citizens Energy Communities (CECs). Both new collective ventures require a minimum of 30 members, which is an increase from the five members required under the previous law. The proposed activities of RECs include production, consumption, storage, and sale of electricity from renewable sources, and they can apply virtual -net metering from RES production units to meet their members’ energy needs and consumers living below the poverty line.

The CECs must undertake at least one of the following activities: production, self-consumption or sale of electricity from renewable sources, storage, distribution and supply of electricity, cumulative representation, provision of flexibility and balancing, as well as provision of energy efficiency, charging services for electric vehicles, and other energy services to its members. They will be able to sell, store, distribute, and procure "green" electricity, as well as own, introduce, buy, or lease distribution networks and manage them autonomously. They will also provide other services such as Demand Response, and energy efficiency services.

The new law also provides additional regulations to facilitate the activities of new energy communities, such as the use of public funds for financial support, inclusion of energy communities in the Development Law as a distinct form of cooperative organization, limiting the percentage of profits that can be distributed to members, legislation of electric grid capacity for energy and virtual net-metering projects, the connection of virtual net-metering projects to the High Voltage grid, and the removal of the obligation to belong to the same provider for implementing virtual net metering. Additionally, the new law addresses issues surrounding self-production for apartment buildings, prohibits the transfer of producer certificates and other licenses, and allows energy communities to manage micro-grids autonomously.

The new law apart from providing incentives for the new types of communities, introduces restrictions on the previous law's communities' activities, leading the latter to transition to one of the two new legal forms. Therefore, the new law also provides for transitional provisions to facilitate the transitional period.

5 Energy communities and their potential to alleviate energy poverty

Up until now, efforts to alleviate energy poverty have mainly focused on providing financial assistance, but identifying energy poor individuals or those experiencing energy poverty is challenging due to the multifaceted nature of the issue [3], [7]. Indicators have been developed to better identify them, and social tariffs and subsidies can offer short-term relief but do not fully address the problem [22]. Alternatively, a bottom-up approach can empower energy poor citizens to leverage innovative financing schemes or join energy communities. Small-scale energy efficiency interventions and behavioral changes can also provide temporary relief. Large-scale interventions require specific schemes or innovative financing to fund them. Actions by energy communities, a type of community energy initiatives, can enhance energy democracy [24], and the Clean Energy for all Europeans packages can pave the way for national-level plans to introduce energy communities. Leveraging innovative financing can establish energy communities primarily composed of citizens and local enterprises. Combining both approaches can lead to a fair and inclusive energy transition, addressing energy poverty and enhancing energy democracy by involving citizens in energy production and providing clean and affordable energy to all [47].

5.1 A review of sectors for community energy actions against energy poverty

In recent years, there has been a growing interest in community energy actions as a potential solution to alleviate energy poverty. However, despite the increasing attention, there are not many examples of successful community energy actions to address energy poverty. This chapter provides a review of community energy actions that have been implemented to address energy poverty, highlighting the limited number of successful case studies. According to Bode, A.[12], community energy has the potential to address energy poverty, but its impact is limited by a variety of factors such as funding, policies, and regulations. Nonetheless, the few successful examples of community energy actions can serve as inspiring models for other communities facing similar energy poverty challenges. Six categories have been identified in which the community energy actions can be listed (fig.1).

Fig. 1. Identified categories of Energy Poverty alleviation actions promoted by Energy Communities (elaborated by the authors).

Provision of clean and cheap energy

According to the European Commission [34], energy cooperatives (ECs) can provide clean and cheap energy to vulnerable households. For example, in Germany, the EC Energiegewinner produces renewable energy and allocates a portion of it to cover their energy needs [28]. This indirect benefit can result in financial savings for the cooperative's members, including vulnerable households. Moreover, Ecs can provide free access to energy for energy-poor households through net metering. For instance, the

Belgian'EC Ecopower [50] allows its members to produce their own renewable energy and sell excess energy back to the grid. This excess energy can be used to offset the energy 'Ills of energy-poor households in the community, resulting in significant financial savings [27]. Furthermore, Ecs acting as energy providers can also benefit energy-poor households by preventing power cuts. For instance, in Spain, the EC Som Energia supplies electricity to its members, including vulnerable households. As a result, power cuts to energy-poor households who are members of the community can be suspended, providing a reliable source of energy, and reducing financial stress [46].

Building Energy retrofits

According to current literature, Energy Communities are actively promoting initiatives aimed at enhancing the energy efficiency of buildings. These initiatives are often subsidized or supported by financial incentives provided by the community. The economic benefits are frequently prioritized towards energy-poor households or social housing, with the objective of improving their living conditions. Additionally, in collaboration with energy providers, Energy Communities are implementing programs to incentivize the reduction of energy consumption, with the aim of redirecting the funds saved towards energy retrofit projects [2], [39].

Social Solidarity and Inclusivity enhancement

Energy poverty often affects vulnerable and marginalized groups in society, leading to social exclusion and stigmatization (Thomson et al. 2019). However, energy communities can promote social solidarity and inclusivity by providing information and equal participation opportunities to all [5], [6], [8], [9]. For example, the Plymouth Energy Community in the UK engages with local residents through information events and social media, providing a platform for discussion and collaboration on energy issues [20]. This has helped to break down social barriers and improve energy access for vulnerable households [20]. Similarly, the Energiegewinner energy cooperative in Germany provides a network of suppliers and consumers, offering benefits such as discounts and special prices [2], [28]. Within this framework, energy-poor households can have their needs monitored and reported to authorities for immediate support, as demonstrated in Greece [15]. By promoting inclusivity and empowering marginalized groups, energy communities can create a more just and equitable energy system [24].

Financial support to cover energy costs

Within the context of Energy Communities (Ecs), various measures are employed to alleviate energy poverty among vulnerable households. One such measure is the provision of discounts, allowances, or the suspension of energy bill payments for a specific period of time [15]. Another approach involves the collection of funds from EC members for direct distribution to energy-poor households or for the implementation of actions aimed at mitigating energy poverty. These funds can be in the form of collective funds, revolving funds, micro-sponsorships of members in paying their electric bills, or crowdfunding campaigns [7]. In addition, some local authorities may temporarily cover the energy debts of vulnerable households to ensure a continuous supply of electricity and energy, with the support of Ecs (Selvakkumaran, S., & Ahlgren, E. O., 2017). Finally, vulnerable households often have the opportunity to become members of Ecs with a very small amount or free of charge.

Job creation

Energy Communities have developed renewable projects create job opportunities that are accessible to everyone in the local communities [21]. These opportunities range from internships to permanent positions and cater to the needs of the community. Through the involvement of experts, vulnerable members of society are trained to secure a stable income while also contributing to society by actively participating in these Energy Communities.

Training – Consulting – Capacity building

Energy Communities often provide support to vulnerable members by offering free energy audits and energy certificates, along with recommendations for improvements. These services are often accompanied by free studies for the installation of renewable energy systems and energy upgrades in energy-poor [33]. To help households adopt more energy-efficient behaviors, Energy Communities also organize training seminars, energy efficiency workshops, and offer technological tools for personalized energy-saving tips [10]. Some Energy Communities even have specially trained consultants, such as municipal employees, who provide information on participation in Energy Communities, as well as advice on improving domestic energy behavior and implementing beneficial energy actions in energy-poor households.

5.2 Successful examples of energy poverty alleviation efforts by collective energy initiatives and communities across Europe

Collective energy initiatives and communities have emerged as a promising solution to this problem, with many successful examples of energy poverty alleviation efforts across Europe. Some successful examples of EC that have developed energy poverty alleviation actions are:

Coopérnico, Portugal [25]: Coopérnico is a Portuguese energy cooperative based in Lisbon, established in 2013 with the primary objective of alleviating energy poverty through the development of renewable energy projects. With a membership of over 1,400, Coopérnico [42] focuses on developing community-owned renewable energy projects, including solar PV, wind power, and energy storage solutions, while collaborating closely with local communities. By generating revenue from these projects, the cooperative provides low-cost energy to low-income households and offers energy efficiency advice to further reduce energy bills. Coopérnico's efforts in reducing energy poverty not only benefit the community but also promote the transition to a sustainable energy system, which aligns with the cooperative's goal of developing 100% renewable energy projects owned and controlled by local communities. Coopérnico serves as a successful example of how energy communities can combat energy poverty by utilizing renewable energy sources and involving local communities in the process [25], [26], [42].

Energy Local, UK [29]: The main objective of Energy Local is to help communities develop local energy projects that generate renewable energy and provide low-cost energy to residents. The initiative achieves this by working with local communities to identify suitable locations for renewable energy projects and helping to secure funding and support for these projects. Once the renewable energy projects are developed, Energy Local helps to establish a local energy trading network that enables residents to buy and sell energy at a fair price. The initiative also provides energy efficiency advice and support to low-income households to help them reduce their energy bills. Energy Local has been successful in reducing energy bills for thousands of households in the UK. For example, in Bethesda, Wales, a community-owned hydroelectric project developed with the help of Energy Local has provided low-cost energy to local residents, reducing their energy bills by up to 50% (Energy Local case study on the Bethesda community-owned hydroelectric project).

Energiegewinner, Germany [28]: Energiegewinner is a German energy cooperative that was founded in 2011 with the goal of promoting the development of renewable energy projects and supporting the energy transition in Germany. The cooperative is based in the city of Cologne and has around 2,000 members. One of the main objectives of Energiegewinner is to reduce energy poverty by providing low-cost energy to low-income households. The cooperative achieves this by developing community-owned renewable energy projects and using the revenue generated to provide low-cost energy to its members. Energiegewinner also provides energy efficiency advice and support to low-income households to help them reduce their energy bills. The renewable energy projects developed by Energiegewinner include solar PV, wind power, and biomass projects, as well as energy storage solutions. The cooperative works closely with local communities to identify suitable locations for its projects and involves local residents in the planning and implementation of the projects.

Ecopower, Belgium [50]: The Ecopower Energy Community in Belgium is a cooperative organization that focuses on promoting renewable energy production and tackling energy poverty. Founded in 1991, it emerged as a grassroots movement driven by the desire to shift towards sustainable energy sources and democratize energy ownership. The community's main goals include developing, owning, and operating renewable energy projects, as well as empowering local communities to actively participate in the energy transition. Ecopower engages in various actions, such as investing in wind, solar, and hydropower projects, providing affordable and locally-produced green energy to its members, and advocating for renewable energy policies. One of its key initiatives to alleviate energy poverty is through its social fund, which provides financial assistance to vulnerable households for their energy bills. By promoting renewable energy, community ownership, and social solidarity, Ecopower aims to create a more sustainable and equitable energy system in Belgium, while actively addressing energy poverty and promoting energy justice.

5.3 Actions that Greek Energy Communities can develop to Fight Energy Poverty

In this part, the actions, that energy communities in Greece can take to help fight energy poverty, are identified, and categorized in the six categories described above. These proposed actions are in alignment with the current legal framework and can serve as a blueprint for the Greek energy communities who make efforts against the phenomenon. The following list is not exhaustive and strictly defined, as the proposed actions need to be customized to each local context that may be implemented.

Table 1. List of actions that Greek Energy Communities can develop to Fight Energy Poverty

Energy Communities actions to mitigate Energy Poverty		
Category	Type of action	Detailed description
Clean and cheap energy supply	Excess energy provision	Offering support to energy-poor households by providing surplus generated energy (usually through energy credits) in cases where surplus energy has been produced.
	Disposition of part of the generated energy	Disposition of part of the generated energy of the cooperative to energy-poor households.
	Uninterrupted power supply	Suspension of power cuts for energy-poor households that are members of the cooperative. This action can only be taken if the energy cooperative operates as an energy provider for its members.
Buildings' Energy retrofits	Energy retrofits in homes	Implementation of energy retrofits actions in homes. Providing financial resources from the energy community to promote energy upgrade or savings projects in energy-vulnerable households.
	Energy retrofits in social housing buildings	Implementation of energy retrofits actions in social housing complexes. Providing financial resources from the energy community to promote energy upgrade or savings projects in social housing complexes.
	Partnerships with electricity providers for funding energy upgrades	Providing incentives to reduce energy consumption in order to use the saved funds for financing energy retrofits works.
Social Solidarity and Inclusivity enhancement	Addressing social exclusion	Encouraging participation of energy-poor households (which are usually economically vulnerable) in collective schemes and community actions, empowering them to seek networking, participation, and employment opportunities.
	Empowerment for participation in a fair energy transition	Participation in decision-making and planning bodies/committees of the energy community, thus fostering the energy democracy.

	Consumer cooperative	Creating a local network of consumers and suppliers aiming for local discounts on businesses, individuals, and communities, indirectly contributing both to the reduction of energy costs and energy efficient products, as well as the revival of the local economy.
	Partnerships with local organizations and government agencies to provide a solidarity safety net	Knowledge of the specific needs of the EC energy-poor members, thus providing complete information to the public authorities to act more quickly and intensely against energy poverty when needed
Financial support to cover energy costs	Reduced energy prices	Reduced or low prices for the energy supply to energy poor households, when the energy community acts as an energy provider, or collectively procures electricity for its members.
	Financial support through the collective fund	Offering money directly to cover energy costs for energy-poor individuals, or directly covering part or all of their energy bill, through the energy cooperative fund or another specialized fund dedicated to mitigating energy poverty.
	Financial support through microgrants	Periodic collection of funds through microgrants from members of the energy community or non-members, to contribute to covering the emergent energy costs of energy-poor households.
	Payment Suspension	Providing the option of suspending payment of energy bills for vulnerable households for a period of time, when the energy community operates as an electricity provider or collectively supplies energy to its members.
	Partial coverage of energy costs through partnerships with local authorities	Providing support to local authorities (municipalities, regions) in cases where the local authorities themselves undertake the support of energy-poor households, usually by temporarily covering the energy debts of these households and ensuring the provision of energy regardless of their energy debts.

	Free or low-cost participation in the energy community	Coverage of participation expenses (shares, subscription, etc.) in the energy community for low-income households, so that they can benefit from the broader advantages that members of a community have, such as collective procurement of energy products at preferential prices, consultation etc.
	Crowdfunding campaigns	Development of crowdfunding campaigns aimed at raising funds for actions and projects (e.g., renewable energy units for virtual energy aggregation) specifically focused on mitigating energy poverty.
	Revolving funds	Creation of special revolving funds to finance actions and projects that will generate revenue, which will be partially channeled towards new projects (that will yield new revenues) and partially towards mitigating energy poverty.
Jobs creation	Internships	Offering internships to members of energy-poor households
	Permanent jobs	Offering permanent job positions to members of energy-poor households.
Training – Consulting – Capacity building-awareness raising	Development of education, information, and decision-making tools.	Development of tools aimed at supporting members to reduce energy consumption. The tools provide capabilities for measuring consumption and understanding it and reducing energy consumption while maintaining the same level of comfort through customized advice provided through the software.
	Educational sessions and user meetings	Educational sessions, seminars, and user meetings, either in-person or online

	Energy audits	Offering free energy audits and energy certificates to vulnerable households, accompanied by proposals for improvements and energy efficiency measures.
	Maturation of new RES projects or energy efficiency measures in homes	Free preparation of studies for the installation of RES and energy upgrading of buildings in energy-poor households.
	Customized Household consultation	Information on energy actions or financing tools in which household members can participate. Personalized support for choosing an electricity provider based on the household's needs.
	Information and transparency in participation terms.	Development of a safe and transparent framework for the terms of contracts provided by an energy community as a supplier and providing detailed information on those terms.
	Training of municipal staff to address energy poverty.	Training of municipality staff to provide energy-saving advice and support to energy-poor households, or the establishment of an energy poverty alleviation office.
	Mapping the local context	Identification of the specific needs the energy poor households face in a specific area, thus removing barriers and challenges for participating in an energy community and receiving customized support by local authorities.
	Awareness raising	open educational campaigns, workshops, and events to help society understand the causes and consequences of energy poverty, and empower them to take action to address this issue through collective efforts and community-based solutions

5.4 Challenges to implement energy poverty alleviation actions

While energy communities offer a promising path towards a more sustainable energy future, they face several barriers and challenges. In this response, the most significant barriers energy communities face in incorporating energy poverty mitigation actions in their activities, include lack of funding, regulatory barriers, technical expertise, lack of community engagement, scale, and political will. Understanding these barriers is critical for developing effective policies and programs that can support and enable the growth of energy communities:

Lack of funding: One of the biggest barriers to energy communities is the lack of funding. Many energy communities are community-led initiatives that rely on volunteers and donations, which can make it difficult to secure the necessary funding to implement energy poverty alleviation programs [5].

Regulatory barriers: Regulatory barriers includes issues with permits and licenses, grid access, and energy market rules. These barriers can make it difficult for energy communities to generate and distribute renewable energy or access affordable energy sources to energy poor households [6].

Technical expertise: Many energy communities lack the technical expertise needed to implement energy poverty alleviation programs. This includes knowledge of energy efficiency measures, renewable energy technologies, and energy management systems. Without this expertise, it can be difficult to design and implement effective programs [20].

Lack of community engagement: Community engagement is essential for energy communities, but it can be challenging to get people on board. This includes issues with communication, outreach, and engagement. Some communities may not be aware of the benefits of energy poverty alleviation programs or may be resistant to change [11].

Scale: Energy communities often operate on a small scale, which can limit their impact on energy poverty. Scaling up these initiatives can be challenging and require significant resources and expertise [14].

Lack of Political will: Finally, political will can be a barrier to energy communities addressing energy poverty. Government policies and programs can have a significant impact on energy poverty, but they may not always prioritize community-led initiatives. Without support from policymakers, it can be difficult for energy communities to have a significant impact [16].

In Greece, similar problems are arising [45], despite the positive aspects of the legal framework. There are still several ambiguities, many possibilities are described, but it has not yet been determined how they can be implemented in practice. Additionally, financing is not easily accessible for energy communities, as there are no available banking programs for cooperatives, especially for a recently established organization that does not own property. The expansion of the framework for the self-consumption of renewable energy sources at a collective level beyond energy cooperatives should be examined, including unions, etc.

6 Conclusions

Energy communities contribute significantly to the energy transition by promoting the use of clean energy sources and reducing reliance on fossil fuels. Energy communities also play a vital role in advancing energy democracy by empowering individuals and local communities to take control of their energy supply. By generating clean energy locally, energy communities also contribute to environmental protection and reduce greenhouse gas emissions. Additionally, energy communities can help alleviate energy poverty by providing affordable and accessible energy to underserved communities. Overall, energy communities are a promising model for achieving a sustainable and equitable energy future.

Regarding energy poverty, an Energy Community can take actions to support energy-vulnerable households of a specific area. In this paper, various relevant successful cases across Europe were explored, and feasible actions for the Greek context were identified and categorized. Briefly, Ecs in Greece can contribute a) Financially (distribution of a percentage of funds collected through various means and their allocation to energy-poor residents or the development of projects that support them), b) Energy-related (provision of part of the energy produced to cover the energy needs of vulnerable residents), c) Professionally (new job positions, practical training), d) Consulting-training (seminars, workshops, personalized advice, meetings, etc.), e) Technologically (tools to increase energy efficiency or improve energy behavior, building retrofits) and f) Socially (sense of belonging, solidarity, participation, support for vulnerable households in the social context).

However, energy communities face various obstacles, such as inadequate funding, technical know-how, regulatory restrictions, and community participation. Policymakers and stakeholders can help overcome these challenges by supporting energy communities through favorable policies, technical support, and funding opportunities. Collaboration between various stakeholders, including energy communities, local authorities, and NGOs, can also help overcome these barriers and implement effective energy poverty alleviation programs.

Overall, the study emphasizes the potential of energy communities in mitigating energy poverty in Greece and suggests ways they can take action to address the issue. By working together with the local communities, energy communities can promote sustainable development, tackle energy poverty, and create a fairer and more robust energy system.

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An ESG materiality methodology combining criterion level and sector-based approaches

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Abstract. As the Environmnetal, Social, and Governance (ESG) principles are rapidly becoming critical in the decision making process of investment undertaking, companies must deal with ESG reporting, either to fulfil obligatory requirements according to EU legislation, or to stay competitive and in line with the investing trends. In the market, several ESG rating methodologies exist consisting of numerous criteria and indicators that companies must consider in their reporting. Nevertheless, neither all ESG rating frameworks consider the same criteria, nor do all criteria have the same materiality weighting when estimating the final ESG rating. Thus, the establishment of a standardised and normalised ESG criteria materiality framework is considered crucial. This will enable the fine-tuning and calibration of the ESG evaluation, with materiality values that reflect accordingly the significance of the most important criteria. In addition, this methodology will enhance the comparability of the results of the different companies' evaluations while creating a harmonised framework. The present paper introduces an integrated methodology for the estimation of the ESG materiality factors by putting emphasis on the most frequent criteria of the main economic sectors. The methodology analyses data from several sources, including academic papers and methodologies, companies' reports and globally established rating frameworks. The proposed approach results in the estimation of the materiality values for each criterion of a specific ESG rating scorecard, as well as introduces an overview of the materiality issues for each economic sector.

Keywords: ESG, ESG materiality, performance measurement, risk management, sustainable finance,

1 Introduction

Investors, funds, and financial institutions are increasingly considering non-financial information to guide their investment decision-making [1]. Therefore, emphasis has been put on the Environmental, Social and Governance (ESG) performance of companies. Companies that demonstrate good performance in ESG-related matters and consistently disclose ESG information, showcase enhanced transparency and reap the benefits of better access to funding as well as more favourable financing terms [2]. For that reason, many ESG methodologies have been developed by several reporting and consulting entities and the number of rating agencies that provide ESG information and assessments has grown significantly. Nevertheless, the lack of a concrete ESG framework creates discrepancies among the reporting standards while blurring the lines on the actual ESG performance of the companies under assessment [3].

In general, materiality refers to the relevance of the disclosure information for stakeholder analysis and decision making. The materiality concept of accounting is an accounting convention that refers the relative importance or significance of an item to an informed decision maker [4]. For instance, if a minor item has the impact of changing a profit figure into a loss figure, then it will be considered material regardless of how small the amount is. Similarly, if by including a transaction, a ratio that needs to comply with changes, it would be considered material [5].

Regarding sustainability, materiality refers to the level of importance that an entity gives to certain sustainability issues in terms of its investment strategy, its business model or its product development [6]. In the context of sustainability reporting, double materiality is gaining momentum since it reflects the essence of sustainable development and long-term value creation. Double materiality consists of the contexts of financial materiality and impact materiality affecting the firm's operational performance and financial health [7]. Financial materiality deals with information on economic value creation at the level of the reporting company for the benefit of investors or shareholders [8], whereas impact materiality focuses on information on the reporting company's impact on the economy, environment, and people for the benefit of multiple stakeholders [9].

Academic investigation of materiality reflects the diverse aspects of this important concept [10]. In literature, various materiality analyses have been performed, both at an academic level [1], [11-13] and in a business-oriented framework [14-16]. Materiality can affect the accuracy and inclusiveness of ESG scores and ratings [17], while enhancing the ambiguity around rating divergence among the different rating agencies and systems. When it comes to the final ESG reporting, not all firms are able to report the same criteria, nor do all criteria have the same materiality. Therefore, it becomes necessary to provide a framework that can determine the materiality of reported indicators for a company in a standardised manner.

Several materiality methodologies exist, mostly developed by consulting, and reporting companies, thoroughly introduced in the following section of the present paper. Alhtough, the scientific community has demonstrated interest for identifying, analysing and normalising existing materiality methodologies, while also attempts have been made to combine and explore new approaches. Busco et al. [18] realised a preliminary analysis of Sustainability Accounting Standards Board (SASB) reporting, while Madison and Schiehll [19] analysed the effect of financial materiality on ESG performance assessment. Garst et al. [20] focused their research on identifying ESG topics for sustainability reports, within the scope of materiality assessment. To the best of our knowledge, the number of scientific publications that introduce new approaches with regards to materiality assessment are limited. The methodology described in this paper introduces a holistic approach in materiality assessment, taking into account real data from businesses in order to establish and fine-tune the methodology, while providing a normalised approach.

The methodology introduces a typology, introducing an integrated process for estimating the ESG Materiality of the most common criteria of the major economic sectors. The ESG materiality has been structured in two distinct levels: Economy and Industry-dependent and Performance and Operation Criteria-dependent. The typology identifies and analyses existing standards, in combination with data from businesses to estimate the Industry-dependent materiality weighting per E, S, G pillar. Each organisation needs to determine its material topics according to specific circumstances, such as its business model. Nevertheless, specific topics can be identified as likely material for organisations in a given sector. Data from various sources, including academic research, business reports, and similar approaches, are analysed to conclude a concrete process, producing normalised results. In order to test the methodology, an application has been realised in the hospitality sector.

Apart from this introductory section, the rest of the paper is organised as follows: Section 2 holds the analysis of the methodology, including tables listing the criteria and weight used. Section 3 describes the application of the methodology in the hospitality sector, while Section 4 holds the paper's Conclusions.

2 Methodology

The ESG materiality has been structured in two distinct levels: Economy and Industry dependent materiality and Performance and Operation Criteria dependent materiality. This categorization is necessary to ensure that the materiality values assigned to each criterion accurately reflect its significance in a specific economic sector. Economy and Industry dependent materiality considers factors such as the economic sector, geography, and industry-specific risks, which influence the materiality of ESG criteria. On the other hand, Performance and Operation criteria dependent materiality focuses on factors that relate to a company's performance and operations, such as emissions, waste management, and labor practices. By categorizing materiality into these two categories, the proposed methodology provides a more nuanced and accurate assessment of ESG performance, enhancing the comparability of results between different companies and sectors. Overall, this classification scheme ensures that the materiality values assigned to each criterion accurately reflect the significance of the most important criteria in a specific economic sector, leading to a more effective ESG evaluation. In Figure 1, the complex systemic interaction of ESG pillars, materiality criteria, business inputs and the respective financial impact is presented.

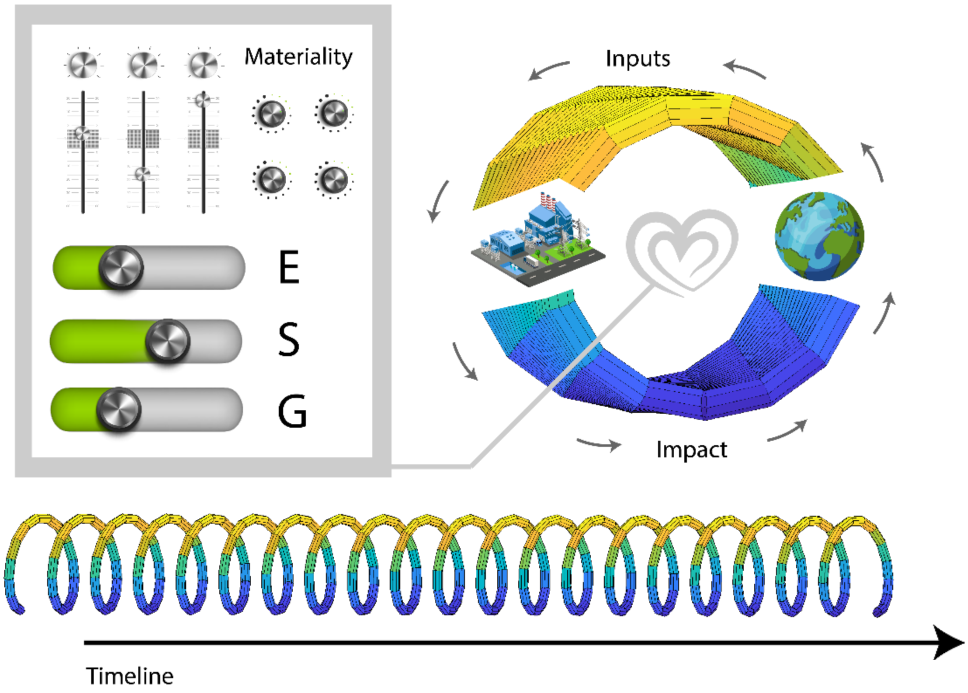

Fig. 1. Visualisation of the complex systemic interaction of ESG pillars, materiality criteria, business inputs and the respective financial impact.

2.1 Economy and industry dependent materiality

Materiality constitutes a key concept that helps companies to connect the dots between sustainability disclosure standards, stakeholders' expectations, and business strategy. The material sustainability issues that a company targets should tie back to the company's core, like its business model and purpose, and provide the initiatives to drive positive environmental change and organisational performance improvement. Mapping the material issues plays a crucial role both in the preparation of the disclosures and the verification by an auditor, since particular information is considered as material if it could influence the decision making of stakeholders in respect of the reporting company. Thus, each company should proceed with a materiality market screen that takes into account its specific circumstances, like geographic, cultural, and legal operating context; ownership structure; and the nature of its impacts while analysing industry benchmarks, peers, and leading sustainability standards, which will help provide an initial universe of materiality issues to select from.

Material topics in ESG vary from industry to industry depending on the specific risks and opportunities each sector has. For example, the Information and Communication Technologies (ICT) sector considers as material issue the cybersecurity vulnerabilities while the healthcare sector might have material issues concerning disparities in patient care and medication distribution. Thus, a one-size-fits-all approach will dilute impact since the material indicators of each company's sector and specific context needs adjustment stemming from a bottom-up analysis.

Moreover, materiality analysis heavily relies on the competitive landscape since investors and other stakeholders shape the needs and expectations of each sector to accomplish financial stability. Therefore, it is crucial that each entity understands what its peers are focusing on when it comes to ESG and sustainability, mapping successfully its materiality issues. Companies that fully consider materiality create stronger, more resilient, and thoughtful businesses that can outperform their competitors with regards to addressing ESG impacts, risks, and opportunities and better inform all industry players, like investors and regulators.

An initial analysis of the various industries (sectors) has been realised to extract materiality weightings for each sector. The analysis consisted of a rigorous literature review, primarily focusing on similar methodologies and reports. The review included the SASB sustainability standards and materiality analysis [16], the ESG Risk Atlas of Standard and Poor's (S&P) Global Ratings [21], Morgan Stanley Capital International (MSCI) ESG Ratings [14] and Global Reporting Initiative (GRI) Standards [22]. It should be highlighted that a correspondence between the industry classification used by the MSCI ESG Ratings, the Global Industry Classification Standard System (GICS), and the industry classification proposed by the SASB's financial materiality framework, the Sustainable Industry Classification System (SICS), for each sub-industry was established to be able to correlate the materiality factors per industry [23].

A first issue that had to be clarified concerns the degree to which each one of the sustainability dimensions (Environment, Society and Governance) affects the final evaluation score according to each sector's sustainability impacts. To be more precise, each dimension affects the final score in a different weight according to the degree to which a company's enterprise value is exposed to its material issues. The results of thorough research showed that Governance issues are significant material for all entities regardless of their industry and scope of work. This can be attributed to the fact that a successful ESG strategy has as a starting point a strong Governance structure and the right mechanisms to promote a clear strategy, and an effective corporate landscape. A robust Governance structure drives the success of ESG programs, affects investor confidence and influences workplace culture.

Statistical analysis of ESG research ratings and data led to the development of a set of materiality weightings for each industry. The values of the Governance materiality weightings range from 29% to 45% according to each industry's specifications. The total sum of the materiality factors of all sustainability dimensions per industry is equal to 100%.

The results of the analysis are summarised in Table 1, while in Figure 2, the relative position on the ESG spectrum of the industry-dependent materiality vectors of 16 industries is presented.

Table 1. Industry-dependent materiality weighting per E, S, G pillar

Industry No.	E	S	G
Agriculture, Forestry, Fishing, and Mining	40%	29%	31%
Mining and Quarrying	40%	29%	31%
Manufacturing	45%	22%	33%
Energy (Production, Distribution, Trade)	42%	29%	29%
Water and Waste Management	45%	25%	30%
Infrastructure and Construction	38%	25%	37%
Wholesale and Retail Trade	25%	36%	39%
Transportation and Storage	40%	31%	29%
Shipping	40%	31%	29%
ICT	30%	35%	35%
Financial and Insurance Activities	17%	38%	45%
Services	32%	29%	39%
Hotel and Lodging	32%	30%	38%
Public Administration	25%	40%	35%
Health	22%	41%	37%
Real Estate and Real Estate Management	31%	30%	39%

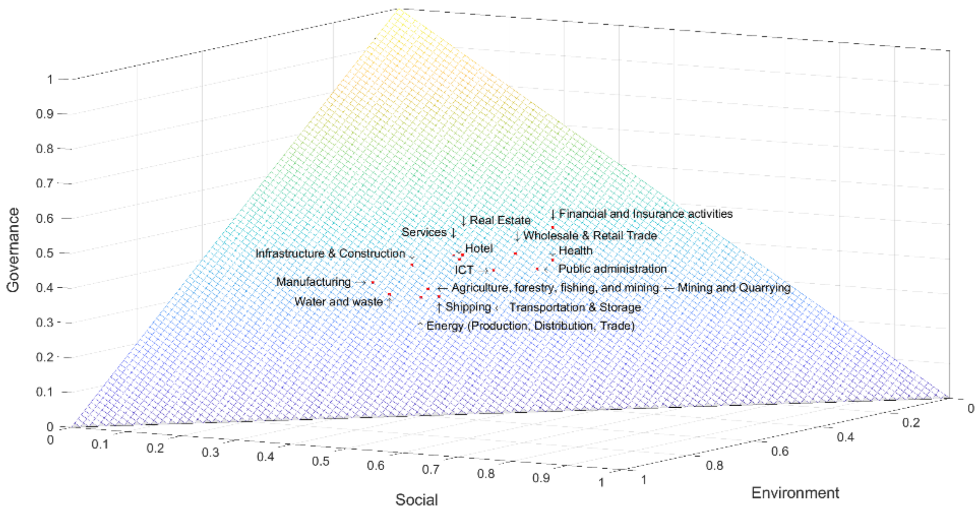

Fig. 2. The relative position of the industry-dependent materiality vectors (16 industries) on the ESG plane.

2.2 Performance and operation criteria dependent materiality

In this section, a criteria-level materiality analysis is performed to extract a materiality index for the specific criteria that contribute to a company's overall ESG rating. Depending on the sustainability impacts of each industry, a specific set of criteria can be developed to depict the most common material issues of the industry. The set of criteria for each industry is derived from an extensive research analysis of publicly available information on companies' ESG scores, as well as a literature review on key sustainability issues per sector. These sets of criteria form an ESG rating framework.

The materiality values of this analysis emerge from actual reports and real ESG data to reflect the actual significance of each criterion and depict the specific circumstances that apply in each sector.

Intensity Values

The first step of defining the criteria-level materiality is an extensive literature review to assign weights for each applicable criterion. These weights are characterised as "Intensity Values" and reflect the importance of each criterion for a specific industry. The literature review performed includes the assessment of academic publications, existing companies' ESG reports, international standards and stakeholders' consultation, so as to define the impact of each criterion on the economy, society and the environment.

The process is performed in two distinct phases. The first phase consists of a separate analysis of the criteria materiality for each reported company of a specific sector. Then, the individual results are aggregated to estimate the materiality of each criterion for the specific sector.

Phase 1– Individual results for each company

An important step of this stage is to create a system of weighting factors to be used when indexing the respective ESG reports on a case-to-case basis. This step results in the creation of materiality matrices. By this means, three distinct levels of materiality were defined with specific factors, called intensity values, to be quantified as follows:

- Low materiality → α
- Medium materiality → β
- High materiality → γ

Example materiality matrices are shown in Figure 3, where the low, medium and high materiality zones can be seen. It should be noted that in Figure 3 (a) the isocurves that demonstrate the same materialisation level appear to be concave, in Figure 3 (b) linear and in Figure 3 (c) convex, indicating the subjective nature of the materiality analysis. Given that a function $f(x)$ is convex on an interval $[a, b]$ if for any two points x_1 and x_2 in $[a, b]$ and any λ where $0 < \lambda < 1$, $f[\lambda x_1 + (1-\lambda)x_2] \leq \lambda f(x_1) + (1-\lambda)f(x_2)$ it can be directly extracted that the mixtures of impact on business and stakeholder interest lead to higher materiality level. Although the latter seems the rational approach, in practice it is common to adopt specific thresholds on each dimension, splitting the plane into quadrants and defining inverted L-shape concave isocurves.

Figure 4 constitutes a sample mathematical extension of the materiality matrix, that utilises functions of two variables for assigning materiality values.

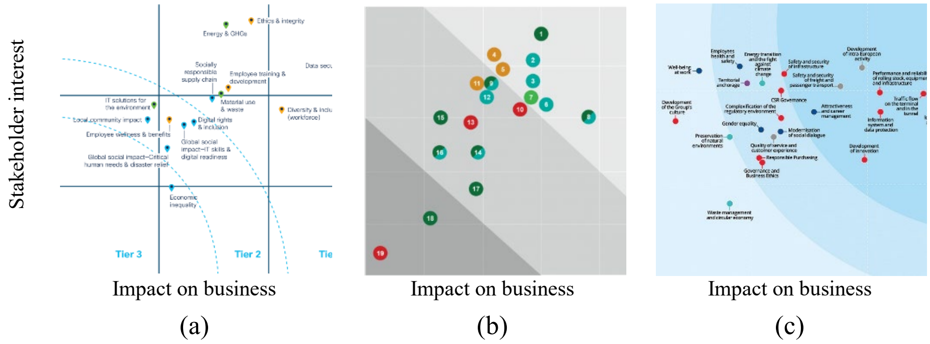

Fig. 3. Materiality matrix examples of different materiality isocurves defining the low, medium and high materiality zones. (a) Concave [24], (b) Linear [25], (c) Convex [26].

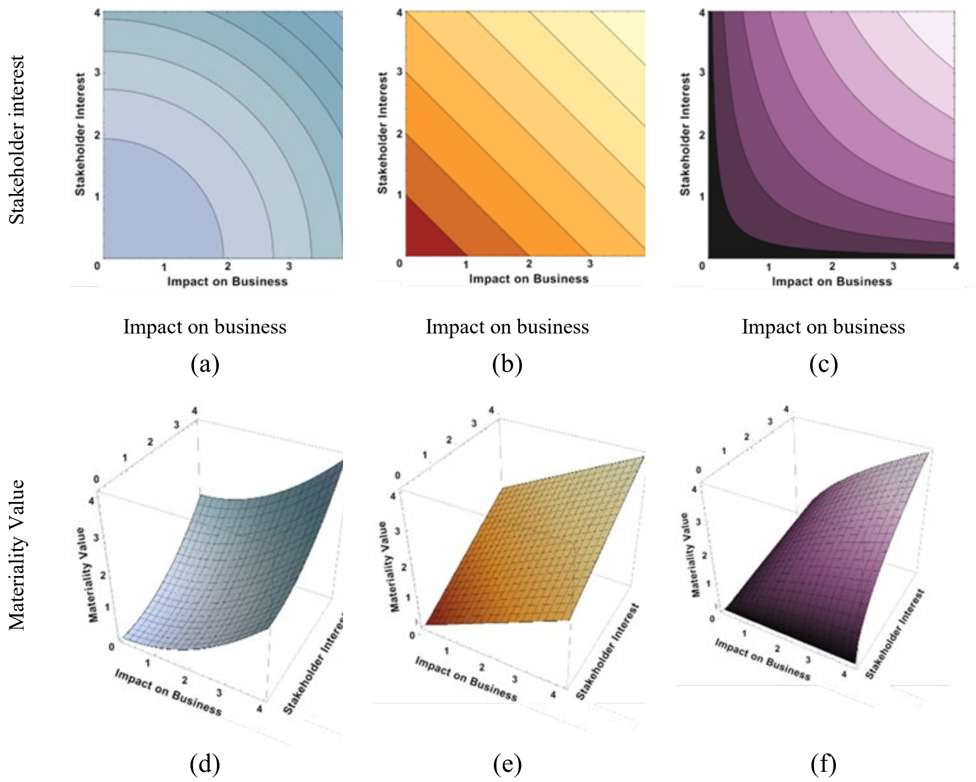

Fig. 4. Contour plots resampling materiality matrices and materiality zones. (a) Concave, (b) Linear, (c) Convex and the corresponding functions (d), (e), (f) that assign a materiality value.

Alternatively, in an effort of barycentric interpolation [27], the suggested methodology proceeds with classification according to the materiality zones (presented in Figure 5), by assigning the distinct values α, β and γ to each indicator according to the zone it belongs.

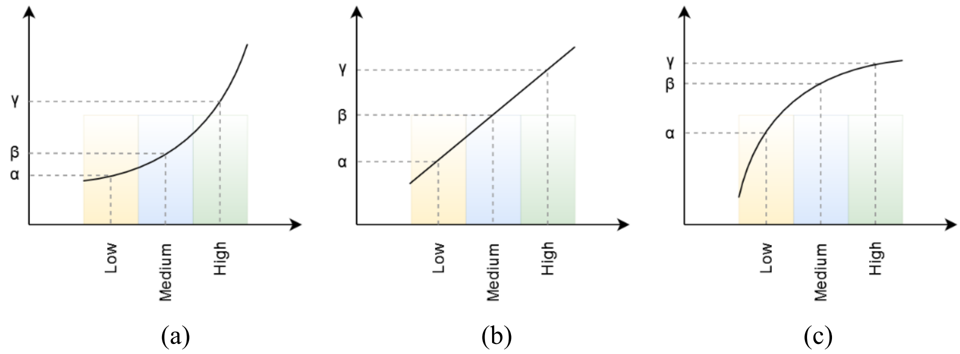

Fig. 5. Value assignment process according to materiality zones. Example cases for (a) Concave, (b) Linear, (c) Convex mapping approaches.

An *intensity value* is assigned for all the criteria reported by each company, with the corresponding *materiality values* calculated for each criterion. The calculation procedure is described below:

i. *Calculation of the Pillar Gravities*

The Pillar Gravities refer to each ESG pillar (E, S & G) and consist of the Intensity Values' total sum for the reported company's indicators (i), e.g. Plastic Waste, GHGs emissions etc. The pillar gravities are used later for the proper normalisation of the materiality values.

$$PG_x = \sum_{i \in \mathcal{H}_x} IV_{x_i} \tag{1}$$

where $x \in \{E, S, G\}$ is the index denoting the corresponding ESG pillar, PG_x is the Pillar Gravity for each ESG pill*ar,* $\mathcal{H}_x$ is the set containing all the criteria of pillar x reported by the company, and IV_{x_i} is the Intensity Value of the criterion i of pillar x.

ii. *Calculation of the Materiality Values*

The materiality value of each criterion i is calculated as the ratio of its Intensity Value over the Pillar Gravity according to the pillar that the specific criterion is included.

$$m_{x_i} = \frac{IV_{x_i}}{PG_x} \tag{2}$$

The materiality values of each ESG Pillar should sum to 1:

$$\sum_{i \in \mathcal{H}_x} m_{x_i} = 1 , \quad \forall x \in \{E, S, G\} \tag{3}$$

Phase 2 – Aggregated sector-based results

In the ESG rating framework under consideration, each industry has a set of criteria that relate to material issues concerning the three pillars of sustainability (E, S, G). To assign materiality Intensity Values to the individual criteria of pillar $x \in \{E, S, G\}$ that compose the scorecard of each industry, it is necessary to aggregate the results of the research analysis mentioned above regarding the ESG materiality analysis of the individual companies operating in the industry. Therefore, an Intensity Value is attributed to each criterion that has been derived as the average of the IV_{x_i} of the corresponding criteria of the companies that have been considered as a sample.

Due to slight divergences among the companies' criteria, further analysis took place to compare the content of each criterion (scope, included actions, measures etc.) so that a correct matching is accomplished among the criteria of the companies, their respective intensity values and the criteria of the ESG framework under consideration.

Let $j \in \mathbb{C}$ denote that the company is part of the sample set of companies considered in the analysis of the sector. The average Intensity Values $\overline{IV}_{x_i}$ is then calculated for each of the criteria reported by the various companies.

$$\overline{IV}_{x_i} = \frac{1}{N} \cdot \sum_{j=1}^{N} IV_{x_i}^{j} \tag{4}$$

where N is the number of companies, i.e. the cardinality of $\mathbb{C}$ and $IV_{x_i}^{j}$ stands for the Intensity Value of the criterion i of pillar x for company j.

Then, similarly to the 1st phase, the average pillar gravities for each one of the 3 ESG pillars are calculated as follows:

$$\overline{PG}_x = \sum_{i \in \mathcal{H}_x} \overline{IV}_{x_i} \tag{5}$$

Finally, the average sector materiality $\widetilde{m}_{x_i}$ of each criterion i for the pillars x is normalised, based on the calculated pillar gravities:

$$\widetilde{m}_{x_i} = \frac{\overline{IV}_{x_i}}{\overline{PG}_x} \tag{6}$$

The results of the calculated pillar gravities are presented in Figure 6.

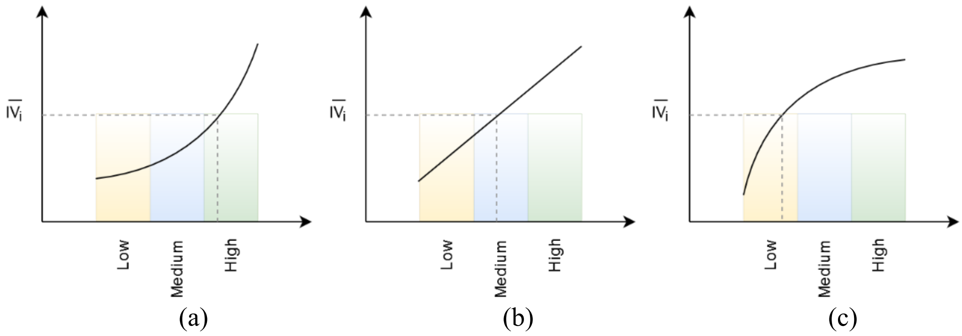

Fig. 6. Reverse engineering assignment process for retrieving the materiality zone for sector-based average intensity values. Example cases for (a) Concave, (b) Linear, (c) Convex mapping approaches.

3 Application in the hospitality industry

The proposed methodology has been applied to the Hotel and Lodging industry [28-31], exploiting data from 6 companies (hotels) that have disclosed ESG information in their sustainability reports.

The ESG scorecard of this specific industry consists of 39 criteria across the 3 sustainability pillars. The intensity values and materiality factors have been calculated based on the methodology analysed in Section 2. A set of indicative criteria are listed in Table 1, while the calculated values regarding the reported Scorecard, the Intensity values and Materiality factors are described in Table 2.

Only a few indicators are included in this paper in order to introduce our approach on how it can be adaptive to different economic industries.

Table 2. Indicative indicators used in the methodological application

No	Code	Pillar	Title
1	CE-1	Environmental	GHG Emissions
2	CE-2	Environmental	Energy Management
3	CE-3	Environmental	Water management
4	CE-4	Environmental	Waste management & Pollution
…	…	…	…
9	HTE-3	Environmental	Biodiversity
13	CS-1	Social	Human Resources
14	CS-2	Social	Health & Safety
15	CS-3	Social	Employee engagement
16	CS-4	Social	Diversity & Inclusion
…	…	…	…
24	HTS - 2	Social	Customer safety
25	HTS - 3	Social	Customer satisfaction
26	CG-1	Governance	Board Diversity & Composition
27	CG-2	Governance	Code of Conduct
28	CG-3	Governance	Ethics (Bribery & Corruption)
…	…	…	…
38	HTG - 2	Governance	Green measures
39	HTG - 3	Governance	Supply chain from local communities

The identified criteria have been mapped to match the respective criteria identified as material issues by the companies in their sustainability reports. Each company reports the criteria using different typologies; hence their content remains the same when investigating further their information regarding their scope, actions taken and/or measures for improvement. Due to this, a thorough mapping took place to set in tune the criteria and correlate the respective data to detect possible overlaps. This procedure is tailored to each case and application, therefore is not possible to create a uniform, automated process to map the criteria of the various reports and perform the process seamlessly.

The intensity values and materiality factors calculated are listed in Table 3.

Table 3. Indicative intensity values and materiality factors

No	Code	Title	Pillar	Average materiality intensity	Average intensity description	Normalised Materiality
1	CE-1	GHG Emissions	Environmental	3.0	High	0.10
2	CE-2	Energy Management	Environmental	2.8	High	0.09
3	CE-3	Water management	Environmental	2.0	Medium	0.07
4	CE-4	Waste Management and Pollution	Environmental	2.3	Medium	0.08
…	…	…	…	…	…	…
9	HTE-3	Biodiversity	Environmental	1.7	Low	0.05
…	…	…	…	…	…	…
13	CS-1	Human Resources	Social	1.0	Low	0.03
14	CS-2	Health and Safety	Social	3.6	High	0.104
15	CS-3	Employee Engagement	Social	3.3	High	0.096
16	CS-4	Diversity and Inclusion	Social	3.3	High	0.096
…	…	…	…	…	…	…
24	HTS - 2	Customer Safety	Social	3.5	High	0.101
25	HTS - 3	Customer Satisfaction	Social	2.7	Medium	0.077
26	CG-1	Board Diversity and Composition	Governance	4.0	High	0.118
27	CG-2	Code of Conduct	Governance	2.0	Medium	0.059
28	CG-3	Ethics (Bribery and Corruption)	Governance	4.0	High	0.118
…	…	…	…	…	…	…
38	HTG - 2	Green Measures	Governance	2.0	Medium	0.059
39	HTG - 3	Supply Chain from Local Communities	Governance	4.0	High	0.118

Table 3 provides information on the calculated materiality intensity, average intensity description and normalized materiality values for various sustainability criteria across the three pillars of ESG (Environmental, Social, Governance) for the Hotel and Lodging industry. The average materiality intensity is a measure of the importance of the sustainability criteria for the industry, with higher values indicating more significant criteria. For instance, GHG Emissions and Energy Management are scored as high priority criteria, while Biodiversity is deemed to be low priority. The average intensity description shows the distinct levels of materiality resulted from the reverse engineering assignment process that is used for retrieving the materiality zone given the sector-based average intensity values. The normalized materiality values are calculated by dividing the average materiality intensity by the sum of all the materiality intensities. They provide a way to compare the relative importance of each criterion. For example, Health and Safety and Supply Chain from Local Communities are deemed to be the material criteria with the highest normalized materiality values of 0.104 and 0.118, respectively. Overall, Table 3 provides a comprehensive view of the sustainability criteria, their importance and the level of performance reported by the hotels, which can help stakeholders identify areas for improvement and monitor progress towards sustainable development goals.

4 Conclusions

The proposed methodology establishes a framework to fine-tune and enhance ESG rating procedures by introducing the materiality context to highlight the significance of the various criteria that comprise an ESG rating. The methodology exploits real data, as provided by business actors, fine-tuning them with the results from other methodologies and reports. By focusing on materiality analysis in the context of ESG consideration, the importance of materiality in connecting sustainability disclosure standards, stakeholder expectations, and business strategy was found inevitable. The analysis involved the identification of the material sustainability issues that are specific to a company's industry and context, and the mapping of these issues to the company's core business model and purpose. The need for a bottom-up analysis of materiality issues, taking into account the unique circumstances of each company, complemented the literature review of existing sustainability standards, such as SASB and GRI, and ESG ratings, such as MSCI, to identify the materiality factors per industry.

To test and fine-tune the methodology, as well as to provide preliminary insights, an application of the methodology has been realised, focused on the hospitality industry. Governance issues are found to be significantly material for all entities, and materiality weightings are established for each industry based on statistical analysis of ESG research ratings and data. The performed criteria-level materiality analysis enabled the development of a set of criteria for each industry that reflect the most common material issues. These criteria are derived from an extensive research analysis of publicly available information on companies' ESG scores and a literature review on key sustainability issues per sector. Ultimately, the methodology aims to help companies identify the material sustainability issues that are most relevant to their industry and context and develop strategies to address them effectively.

The suggested approach can be perceived as an additional instrument and effort in the normalisation and standardisation of the various existing ESG methodologies that aim to support decision makers and business actors in identifying material topics and prioritising subjects of interest. The produced materiality matrices could be exploited to enhance and calibrate existing ESG evaluation frameworks. The methodology outlined aims to provide a systematic approach for companies to identify and prioritize the material sustainability issues that are most relevant to their business.

The key outcomes of this methodology are the identification of materiality issues through a market screen that takes into account the specific circumstances of each company, including its geographic, cultural, and legal operating context, as well as an analysis of industry benchmarks, peers, and leading sustainability standards. Materiality issues are also identified through a criteria-level materiality analysis that assigns weights to each applicable criterion for a specific industry. This process enables companies to understand the specific sustainability risks and opportunities they face and develop strategies to address them effectively. Ultimately, the goal of this methodology is to help companies create stronger, more resilient, and thoughtful businesses that can outperform their competitors with regards to addressing ESG impacts, risks, and opportunities and better inform all industry players, like investors and regulators.

Fuzzy inputs in the model can lead to vagueness in the results and can affect the accuracy of the materiality index. However, the methodology attempts to address this issue by using a comprehensive literature review, stakeholder consultation, and real ESG data to assign weights to each criterion. This helps to mitigate the impact of fuzzy inputs on the overall results. The methodology is sensitive to biased intensity values used for each criterion, as these values directly affect the materiality index. Biased intensity values can lead to incorrect prioritization of material issues and undermine the effectiveness of sustainability initiatives. To minimize this risk, the methodology employs a rigorous and transparent process for assigning intensity values, including extensive research and consultation with stakeholders. Additionally, the methodology involves aggregating individual results from multiple companies to estimate the materiality of each criterion for the specific sector, which helps to reduce the impact of any biased intensity values. Overall, the methodology seeks to ensure that the intensity values used are as accurate and unbiased as possible, to ensure that the materiality index reflects the true sustainability impacts of each industry.

In the context of this methodology, robustness refers to the ability of the model to produce consistent and reliable results even when faced with different input values or data sources. A robust methodology should be able to produce similar results even if the data used in the analysis is incomplete or uncertain. The approach outlined in the paper appears to be robust to a certain extent. For example, it uses a combination of different data sources and analysis techniques to derive the materiality weights for each industry, which helps to reduce the impact of bias in the data. Additionally, a sensitivity analysis could test the impact of different input values on the final results, which would help to identify the factors that are most sensitive to change and adjust the model accordingly. However, there are also some limitations to the methodology's robustness. For example, the intensity values used to weight each criterion are based in certain cases on experts' judgment and may be subject to bias or uncertainty. Additionally, the methodology relies heavily on publicly available data, which may be incomplete or inconsistent. As a result, the authors acknowledge that the results of the analysis should be interpreted with caution, and that further research is needed to validate and refine the methodology.

To address the issue of fuzzy inputs, the methodology could consider the use of alternative methods that can handle uncertainty and imprecision, such as fuzzy logic, fuzzy sets, or probabilistic methods. These methods can provide a more accurate representation of the uncertainty associated with the intensity values used in the analysis. Regarding the issue of biased intensity values, one possible solution is to increase the transparency and inclusiveness of the materiality analysis process. This could involve wider stakeholder consultation and engagement, which could help to identify and correct for potential biases in the intensity values used. Additionally, sensitivity analysis could be performed to assess the robustness of the results to variations in the intensity values.

As for next steps, further research could be conducted to test the sensitivity of the methodology to different input values, such as the weights assigned to each dimension of sustainability (environment, society, governance) or the criteria-level materiality weights. The methodology could also be applied to different industries or contexts to assess its generalizability and identify any necessary adaptations. Finally, ongoing monitoring and evaluation could be put in place to track the performance of the methodology and ensure its continued effectiveness and relevance over time.

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A planar geometrically nonlinear bistable auxetic metamaterial mechanism for programmable energy-saving structures

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Abstract. The EU and its member states have agreed to reduce carbon dioxide emissions. Building operation and construction are the primary contributors to greenhouse gas emissions. Construction products have a huge environmental impact throughout their life cycle and are also the main source of waste generation. The construction sector can not embrace sustainability only by reusing and recycling materials. Adaptable multifunctional materials play a critical role towards energy-saving and green transition. In particular, adaptable structures can significantly reduce the time and cost of manufacture, transport, and construction. Mechanical metamaterials are artificial systems that can produce desired physical and mechanical properties by designing the base cell of which the lattice is composed. A structure that has negative Poisson's ratio is called auxetic and bistability is the property of having two stable equilibrium positions within the range of its motion-deformation. The present study develops a planar bistable auxetic mechanical metamaterial based on a re-entrant arrowhead auxetic topology and analyses the structure's mechanism and its properties. In the paper, we first give the geometric description and then we study the theory for the analysis of the metamaterial mechanism. Finally we present an example of the base cell.

Keywords: Adaptable structure, Mechanical Metamaterial, Mechanism, Bistable Structure, Auxetic Structure, Geometric Nonlinearity.

1 Introduction

1.1 Overview

Structural adaptability is an innovative technique that architecture focuses on to address energy concerns. One way to implement adaptability in structures is to use materials that enables shape transformation. Our structure is focused on eliminating the need for constant energy input to maintain transformation. Metamaterial mechanisms are structures with tailored physical and mechanical properties defined by their architecture rather than their chemical composition [1]. A bistable mechanism has two stable equilibrium positions within its range of motion. It achieves this behaviour by storing energy during part of its motion and then releasing it as the mechanism moves toward a second stable state [2]. The two stable states can be programmed by the base cell design. In this paper we focus on the re-entrant arrowhead auxetic topology [3] and we use it to create a two-dimensional bistable auxetic structure. Materials that have a negative Poisson's ratio when stretched, they become thicker perpendicular to the applied force. Such materials or structures are called auxetic [3]. The term auxetic derives from the Greek word αυξητικός (auxetikos) which means "that which tends to increase" and has its root in the word αύξησις, or auxesis, meaning "increase". Various structures, that present auxetic behaviour, have been studied so far [4-7]. Our structure displays auxetic properties and bistable behaviour as well. If the deformation gradient is large enough then the nonlinear terms of strain tensor cannot be overlooked and the structure exhibits geometric nonlinearity.

1.2 Programmable energy-saving structures

Shape transformation is crucial in many applications ranging from nanoscale to macro scale. There is a need for flexibility in the construction sector. Structures are expensive, energy-intensive and their skin will outlast their original use. Some buildings are more prone to demolition, while others are better suited to redevelopment. Critical to the above is the design and construction of programmable structures that can evolve according to different requirements or be erected in a more energy-efficient manner in various environments such as outer space or deep sea.

2 Base cell

Our model is a linkage-based periodic structure composed by a system of rigid bodies connected with elastic/rotary hinges (revolute joints). The rigid bodies are 1- or 2-dimensional polytopes (i.e. links, triangles) (see Fig.1,2).

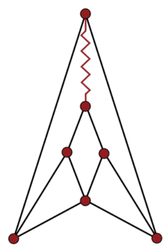

Fig. 1. Base cell

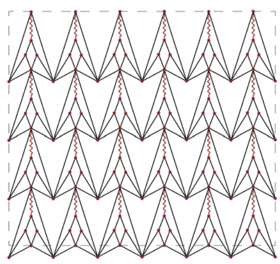

Fig. 2. Lattice structure

2.1 Degrees of freedom

The rigidity of the structure depends on the stiffness of the linear spring. If we consider the linear spring as an undeformed edge then the unit cell is a two-dimensional minimally rigid graph i.e. a Laman graph (our base cell with Nvertices has $2\mathrm{N}-3$edges and no N'-vertex subgraph has more than $2N' - 3$ edges) [8]. The rigidity can also be easily proven by a Henneberg construction (see Fig.3).

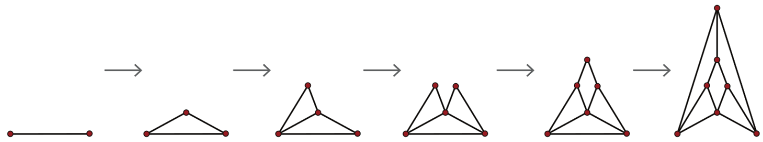

Fig. 3. Henneberg construction.

The deformation mechanism is derived from the elastic rotational joints of the undeformed links and from the stiffness of the linear spring. Using the Chebychev–Grübler–Kutzbach formula $(M = 3(n - 1 - j) + \sum_{i=1}^{j} f_i)$we can calculate the mobility $M(DOF)$ of a system formed from $n$links and $j$joints each with $f_i, (i = 1,\ldots,j)$degrees of freedom. For the present mechanical system $n = 10$, $j = 13$and $f_i, (i = 1,\ldots,13)$thus the mobility of the system is:

$$M = 3(10 - 1 - 13) + \sum_{i=1}^{13} f_i = 1 \tag{1}$$

The mechanical system has 1DoF in 2D space. So, we need only one independent parameter to define the configuration of the kinematic chain. The angle $\theta$is the independent parameter needed.

2.2 Geometry

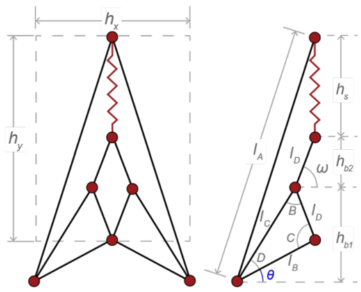

Fig. 4. Base cell dimensions

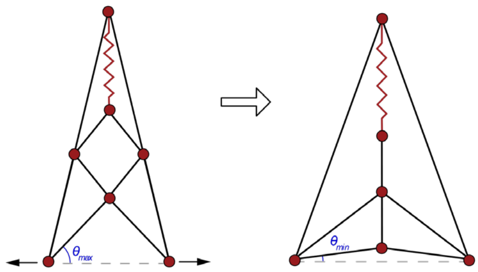

Fig. 5. Mechanism's movement

As illustrated in Fig. 4, the shape and size of this system can be described in terms of θthrough an orthogonal unit cell in e_1e_2-plane with side lengths h_1, h_2given by:

$$h_1 = 2l_B cos\theta,\ h_2 = \sqrt{{l_A}^2 - (l_B cos\theta)^2} - l_B sin\theta \tag{2}$$

Based on the desired outcome of the bistable state, the user can set the following parameters: $l_A, l_B, l_C, \widehat{D}, k_r, k_l$. During the deformation and for physically realistic structures where the triangles do not overlap (see Fig.5), the range $(\theta_{min}, \theta_{max})$of the angle $\theta$is:

$$\theta_{min} = \frac{\pi}{2} - \widehat{D} - \widehat{B}, \theta_{max} = arctan\left(\frac{1}{tan(\widehat{D})} - \frac{l_B}{l_A sin(\widehat{D})}\right)$$

$$\widehat{B} = \begin{cases} arcsin\left(\frac{l_B}{l_D} sin\widehat{D}\right) & if \frac{l_B}{l_C} cos\widehat{D} < 1 \\ \frac{\pi}{2} & if \frac{l_B}{l_C} cos\widehat{D} = 1 \\ \pi - arcsin\left(\frac{l_B}{l_D} sin\widehat{D}\right) & if \frac{l_B}{l_C} cos\widehat{D} > 1 \end{cases} \tag{3}$$

Also, the following manufacturing parameter restrictions must apply:

$$l_B \leq l_A, \widehat{D} \leq arccos\left(\frac{l_B}{l_A}\right), l_C \leq \frac{h_y + 2l_B sin\theta}{2sin(\theta + \widehat{D})} \tag{4}$$

3 Geometrically nonlinear strain theory

3.1 Strain tensor

The displacement vector $(u)$of the mechanism during its deformation without rigid-body translation is the difference between the deformed $(x)$and the undeformed (X)configuration $(u_i = x_i - X_i)$. Thus, the displacement gradient tensor is $\nabla u = u_{i,j} = \frac{\partial(x_i - X_i)}{\partial x_j} = \frac{\partial x_i}{\partial x_j} - \frac{\partial X_i}{\partial x_j} = \delta_{ij} - \frac{\partial X_i}{\partial x_j} = \delta_{ij} - X_{i,j}$. If the displacement gradient is large enough $(\nabla u > 10^{-3})$to invalidate the assumptions of the infinitesimal strain theory $\left(\frac{\partial u_i}{\partial x_j} \neq \frac{\partial u_i}{\partial X_j}\right)$then the body exhibits geometric nonlinearity. According to the above, the finite strain tensor is defined as:

$$\varepsilon_{ij} = \frac{1}{2}\left(\delta_{ij} - X_{k,i}X_{k,j}\right) = \frac{1}{2}\left(\delta_{ij} - \frac{\partial X_k}{\partial x_i}\frac{\partial X_k}{\partial x_j}\right) = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{\partial u_k}{\partial x_i}\frac{\partial u_k}{\partial x_j}\right) \tag{5}$$

The lattice of the present model is a planar structure that cannot shear during deformation $\left(\frac{\partial X_1}{\partial x_2} = \frac{\partial X_2}{\partial x_1} = 0\right)$. Thus, the strain tensor has the form:

$$\varepsilon_{ij} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\left(1 - \left(\frac{\partial X_1}{\partial x_1}\right)^2 - \left(\frac{\partial X_2}{\partial x_1}\right)^2\right) \\ \frac{1}{2}\left(1 - \left(\frac{\partial X_1}{\partial x_2}\right)^2 - \left(\frac{\partial X_2}{\partial x_2}\right)^2\right) \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\left(1 - \left(\frac{\partial X_1}{\partial x_1}\right)^2\right) \\ \frac{1}{2}\left(1 - \left(\frac{\partial X_2}{\partial x_2}\right)^2\right) \\ 0 \end{bmatrix} \tag{6}$$

The domain of $\theta$is a subset of $\left[0,\frac{\pi}{2}\right]$ $\left([\theta_{min},\theta_{max}] \subseteq \left[0,\frac{\pi}{2}\right]\right)$. Utilizing the strain tensor of the continuum body $(\partial X)$to our planar $(h_1 x h_2)$mechanism during $\theta_\alpha = 0$to θ_{max}deformation we get:

$$\varepsilon_1 = \frac{1}{2}\left(1-\left(\frac{h_1(\theta_\alpha)}{h_1(\theta)}\right)^2\right) = \frac{1}{2}\left(1-\left(\frac{2l_B cos0}{2l_B cos\theta}\right)^2\right) = \frac{1}{2}\left(1-\frac{1}{cos^2\theta}\right) = \frac{-tan^2\theta}{2} < 0, \qquad \forall\theta \in \left(0,\frac{\pi}{2}\right] \tag{7}$$

$$\varepsilon_2 = \frac{1}{2}\left(1-\left(\frac{h_2(\theta_\alpha)}{h_2(\theta)}\right)^2\right) = \frac{1}{2}\left(1-\frac{{l_A}^2-{l_B}^2}{\left(\sqrt{{l_A}^2-(l_B cos\theta)^2}-l_B sin\theta\right)^2}\right) \tag{8}$$

$$\varepsilon_2 < 0 \Rightarrow \frac{1}{2}\left(1-\frac{{l_A}^2-{l_B}^2}{\left(\sqrt{{l_A}^2-(l_B cos\theta)^2}-l_B sin\theta\right)^2}\right) < 0 \Rightarrow l_B < l_A \tag{9}$$

This inequality is a manufacturing parameter restriction of the structure (Eq.4). When we deform the mechanism from $\theta_a = 0$to $\theta_{max}$the strain tensor becomes $\varepsilon_1 < 0$and $\varepsilon_2 < 0$. Respectively it turns out that by deforming the mechanism from $\theta_b = \frac{\pi}{2}$towards θ_{min}we get $\varepsilon_1 > 0$and $\varepsilon_2 > 0$. Therefore:

$$\frac{\varepsilon_1}{\varepsilon_2} > 0, \frac{\varepsilon_2}{\varepsilon_1} > 0\ \forall\theta \in [\theta_{min},\theta_{max}] \tag{10}$$

3.2 Poisson's ratio

The Poisson’s ratio $(v)$for a stable, isotropic, linear elastic material must be between $-1.0$and $+0.5$due to the requirement that the modulus of elasticity $(E)$the shear modulus $(G)$and the bulk modulus (B), have positive values, but this is not binding for anisotropic elastic materials [9,10]. In the small strain regime the Poisson's ratio is constant, in large strain this ratio is a scalar function that varies with strain [11, 12]. For our structure according to Eq. 10 the Poisson's ratio is defined as:

$$v_{12} = \frac{-\varepsilon_2}{\varepsilon_1} < 0, v_{21} = \frac{-\varepsilon_1}{\varepsilon_2} < 0,\ \forall\theta \in [\theta_{min},\theta_{max}] \tag{11}$$

4 Mechanism analysis

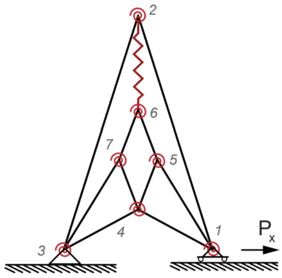

Fig. 6. 2D pseudo rigid body model.

4.1 Potential energy

According to the first law of thermodynamics, in an isolated system where no losses are created in the form of heat $(Q)$and assuming that there is no conversion into kinetic energy $(K)$the total potential energy $(\Pi)$is defined as:

$$\Pi = U - W \tag{12}$$

Where $(U)$is the internal strain energy and $W$is the work done by the external forces.

4.2 Strain energy

To design the bistable structure we construct a planar system of six rigid bodies connected with seven elastic/rotary hinges (revolute joints), as well as one elastic link (i.e. linear spring). According to the 2D pseudo rigid body model (see Fig.6) the strain energy of the base cell consists of the sum of the energy stored in each spring (torsional $U_r$and linear U_l).

$$U = U_l + U_r \tag{13}$$

Strain energy of linear spring. $U_l$is the strain energy from the linear spring, $k_l \left[\frac{N}{m}\right]$is the stiffness constant of the linear spring and $\Delta\psi[m]$is the deformation of the spring.

$$U_l = \frac{1}{2} k_l (\Delta\psi)^2 \tag{14}$$

$$\Delta\psi = \psi(\theta) - \psi(\theta_0),\ \psi = \sqrt{{l_A}^2 - (l_B cos\theta)^2} + l_B sin\theta - 2l_C sin(\theta + \widehat{D}) \tag{15}$$

Strain energy of torsional springs. The strain energy from the torsional springs is the sum of the energy of each individual torsional spring. $k_l \left[\frac{N*m}{rad}\right]$is the stiffness constant of the torsional spring and $\Delta\varphi$is the deflection angle of each spring based on the initial undeformed place $\varphi(\theta_0)$.

$$
\begin{gathered}
U_r = \frac{1}{2}\sum_{i=1}^{7} k_r(\Delta\varphi_i)^2, \Delta\varphi_i = \varphi_i - \varphi_{i0}, i: \{1,2,.\,|.\,7\}, \\
\varphi_1 = \varphi_3 = \theta, \\
\varphi_2 = arcsin\left(\frac{l_B}{l_A} cos\theta\right) \\
\varphi_4 = \pi - 2\theta, \\
\varphi_5 = \varphi_7 = 2(\hat{C} - \theta)
\end{gathered} \tag{16}
$$

4.3 Mechanism's equilibrium

Bistable structure. The storage and release of energy defines the structure's stable equilibrium positions. Equilibrium is established at a point in configuration space when no external forces $P$are required to maintain the structure's position (the work done by the external forces $W$is equal to zero). In these positions the total potential energy of the system has an extrema. $\frac{\partial \Pi}{\partial \theta}\,|_{\theta=\theta_0} = 0$

The equilibrium position is characterized as stable if for every possible small displacement from the equilibrium position the system tends to return to the same position, i.e. the total potential energy is at a local minimum and thus increases during the displacement. $\frac{\partial \Pi}{\partial \theta}\,|_{\theta=\theta_0} > 0$

The equilibrium position is characterized as unstable if for every possible small displacement from the equilibrium position the system tends to move even further away from the initial position, i.e. the total potential energy is at a local maximum and thus decreases during the displacement. $\frac{\partial \Pi}{\partial \theta}\,|_{\theta=\theta_0} < 0$

There are also mechanisms where if the system shifts to a new position, it will remain in that position, that is, each position is an equilibrium position. This balance is characterized as neutral. The potential energy of such a system does not change. To investigate the precise stability of this system, higher order derivatives must be examined.

The above is the energy method and it is based on the Lagrange-Dirichlet theorem, which states that "when the potential energy has a minimum for an equilibrium position, the equilibrium position is stable" [13]. For a structure to be bistable in a given configuration, it must meet three criteria: (α) The function of the potential energy must have three critical points (extrema). (β) The second derivative of potential energy must be positive in two of these solutions, indicating two stable states, while it must be negative in all other solutions, indicating unstable positions. (γ) The two stable positions as well as at least one of the unstable positions must be viable positions (inside the range of its defined motion) [14].

Strain energy of torsional springs. If we remove the linear spring from the structure ($\boldsymbol{U_l} = \boldsymbol{0}$)and $\boldsymbol{k_r}$is chosen to be the only non-zero spring constant, then the internal strain energy consists only of the energy stored in the torsional springs. So, the equilibrium position where the potential energy of the system has an extrema is:

$$
\frac{\partial \Pi}{\partial \theta} = 0 \Rightarrow \frac{\partial U_r}{\partial \theta} = 0 \Rightarrow \sum_{i=1}^{7} k_r(\varphi_i - \varphi_{i0})\frac{\partial \varphi_i}{\partial \theta} = 0 \Rightarrow \varphi_i = \varphi_{i0} \tag{17}
$$

Therefore, for this type of configuration (if we remove the linear spring) the initial undeformed state is the only equilibrium position the mechanism has. The structure does not have a bistable behaviour.

Strain energy of linear spring. If $\boldsymbol{k_l}$is chosen to be the only non-zero spring constant, then the total strain energy results from the strain energy of the linear spring ($\boldsymbol{U} = \boldsymbol{U_l}$). So, the potential energy of the system presents critical points where $\frac{\boldsymbol{\partial \Pi}}{\boldsymbol{\partial \theta}}$ becomes zero or is not defined.

$$\frac{\partial \Pi}{\partial \theta} = 0 \Rightarrow \frac{\partial U_l}{\partial \theta} = 0 \Rightarrow k_l(\psi - \psi_0)\frac{\partial \psi}{\partial \theta} = 0 \Rightarrow \left| \begin{array}{l} \psi - \psi_0 = 0 \\ \dfrac{\partial \psi}{\partial \theta} = 0 \end{array} \right. \tag{18}$$

$$\psi - \psi_0 = 0 \Rightarrow \theta = \theta_0\text{: initial undeformed state.} \tag{19}$$

$$\frac{\partial \psi}{\partial \theta} = 0 \Rightarrow \frac{{l_B}^2 sin(2\theta)}{2\sqrt{{l_A}^2 - (l_B cos\theta)^2}} + l_B cos\theta - 2l_C cos(\theta + \widehat{D}) = 0 \Rightarrow \left| \begin{array}{l} \theta = \theta_1 \\ \theta = \theta_2 \end{array} \right. \tag{20}$$

The three critical points of the function are at $\theta_{0,}\theta_{1,}\theta_2$. Then with the second derivative of the potential energy $\frac{\partial^2 \Pi}{\partial \theta^2}$we find the maxima and minima and thus the stable and unstable equilibrium as stated before.

Total strain energy $\boldsymbol{k_r, k_l > 0}$. In a third case where the stiffness constants of both the torsional and the linear spring are different from zero, the internal strain energy of the mechanism is obtained according to Eq.13. Therefore, for the structure to present bistable behaviour the ratio $\boldsymbol{k_r/k_l}$is:

$$\frac{\partial}{\partial \theta}U = 0 \Rightarrow \frac{k_r}{k_l} = -\Delta\psi \frac{\partial \psi}{\partial \theta}\left(\sum_{i=1}^{7} \Delta\varphi_i \frac{\partial \varphi_i}{\partial \theta}\right)^{-1} \tag{21}$$

4.4 Deformation load

In our structure the strain energy and the complementary strain energy are equal. Thus, from Castigliano's first theorem will get:

$$P = \frac{\partial U}{\partial (x - X)} \Rightarrow P_i = \frac{\partial U}{\partial (h_i(\theta) - h_i(\theta_0))} = \frac{\dfrac{\partial U}{\partial \theta}}{\dfrac{\partial h_i(\theta)}{\partial \theta}} \tag{22}$$

5 Material properties

5.1 Density

Our structure is defined by geometric topological principles without being limited by the length scale of the mechanism. So, we can analyse our structure as a porous medium with the mechanical metamaterial part considered as the skeletal portion of the continuum body and the space in between as the pore network. We will set our base cell as the representative elementary volume of the material which includes the volume of both "phases":

V_α: volume of the mechanism
V_β: volume of the "empty" space
$V_\alpha + V_\beta = V$: bulk volume of the continuum body

For our structure the volume $(V)$is given by: $V = h_1 * h_2 * 1$. Thus, from Eq.2 the expression of the volume becomes:

$$V = 2l_B cos\theta\sqrt{{l_A}^2 - (l_B cos\theta)^2} - l_B^2 sin(2\theta) \tag{23}$$

A particularly important property of materials is the percentage of the volume occupied by their matter. This is the relative density and is the percentage of the mechanism's volume to the bulk volume $(\rho = V_\alpha/V)$. In our structure the volume of the mechanism (V_α)remains constant throughout its deformation. However, the same is not true for bulk volume. So, the relative density fraction in our two stable equilibrium states is:

$$\frac{\rho(\theta_2)}{\rho(\theta_0)} = \frac{V(\theta_0)}{V(\theta_2)} \tag{24}$$

Density and porosity affects properties of materials related to transport phenomena (water absorption, air permeability, thermal and electrical conductivity), mechanical properties and more.

5.2 Stiffness

During the movement of the mechanism the forces acting on it are in equilibrium.

$$\partial U = \partial W \Rightarrow \partial U = P\partial u \Rightarrow \frac{\partial U}{V} = \sigma\partial\varepsilon \tag{25}$$

The mechanical properties of the metamaterial that are necessary to create the transition from one stable position to the second are defined as:

$$\begin{gathered}\frac{\partial U}{V} = \sigma\partial\varepsilon \Rightarrow \sigma_{ij} = \frac{\partial U}{V\partial\varepsilon_{ij}} \Rightarrow \partial\sigma_{ij} = \frac{\partial^2 U}{V\partial\varepsilon_{ij}} \Rightarrow C_{ijkl}\partial\varepsilon_{kl} = \frac{\partial^2 U}{V\partial\varepsilon_{ij}} \Rightarrow C_{ijkl} \\ = \frac{\partial^2 U}{V\partial\varepsilon_{ij}\partial\varepsilon_{kl}} \Rightarrow C_{ijkl} = \frac{\frac{\partial^2 U}{\partial\theta^2}}{V\frac{\partial\varepsilon_{ij}\partial\varepsilon_{kl}}{\partial\theta\partial\theta}}\end{gathered} \tag{26}$$

6 Application

6.1 Geometry

The parameters that define the geometry are:

$$l_A = 15 * 10^{-3}m, l_B = 3 * 10^{-3}m, l_C = 5 * 10^{-3}m, \widehat{D} = \frac{\pi}{6,} k_r = 0 \tag{27}$$

Under the restrictions of the manufacturing parameters (Eq.4) we can state that this is a valid configuration. Based on the above parameters (Eq.27) and Eq.3 we derive that the domain of deformation is:

$$\theta \in [0.49, 0.92](rad) \tag{28}$$

The side lengths (Eq.2) of the base cell at the two extreme positions are:

$$\begin{gathered} h_1 = 2l_B cos\theta \Rightarrow \left| \begin{matrix} h_1(\theta_{min}) = 5.29mm \\ h_1(\theta_{max}) = 3.60mm \end{matrix} \right. \\ h_2 = \sqrt{{l_A}^2 - (l_B cos\theta)^2} - l_B sin\theta \Rightarrow \left| \begin{matrix} h_2(\theta_{min}) = 13.35mm \\ h_2(\theta_{max}) = 12.50mm \end{matrix} \right. \end{gathered} \tag{29}$$

$$\begin{gathered} \left|\frac{\Delta h_1}{h_1}\right| = \left|\frac{h_1(\theta_{min}) - h_1(\theta_{max})}{h_1(\theta_{max})}\right| = 0.32 > 10^{-3} \\ \left|\frac{\Delta h_2}{h_2}\right| = \left|\frac{h_2(\theta_{min}) - h_2(\theta_{max})}{h_2(\theta_{max})}\right| = 0.064 > 10^{-3} \end{gathered} \tag{30}$$

As can be seen, the structure during tension (from the initial undeformed position $\theta_0 \equiv \theta_{max}$we go to θ_{min}) undergoes large deformations.

6.2 Equilibrium positions

Since only the linear spring contributes to the strain energy, then according to Eq.18 the equilibrium positions of the mechanism are:

$$\frac{\partial \Pi}{\partial \theta} = 0 \Rightarrow \frac{\partial U_l}{\partial \theta} = 0 \Rightarrow k_l(\psi - \psi_0)\frac{\partial \psi}{\partial \theta} = 0 \Rightarrow \left| \begin{matrix} \theta_0 = 0.92 \\ \theta_1 = 0.79 \\ \theta_2 = 0.69 \end{matrix} \right. \tag{31}$$

$$\left.\frac{\partial^2 \Pi}{\partial \theta^2}\right|_{\theta=\theta_0} > 0, \quad \left.\frac{\partial^2 \Pi}{\partial \theta^2}\right|_{\theta=\theta_1} < 0, \quad \left.\frac{\partial^2 \Pi}{\partial \theta^2}\right|_{\theta=\theta_2} > 0 \tag{32}$$

In this case our structure will have two stable positions $(\theta_0, \theta_2)$and one unstable (θ_1)within its range of motion. It stores energy during part of its motion $\theta \in$

[0.92,0.79]and then releasing it as the mechanism moves toward a second stable state $\theta \in [0.79,0,69]$.

6.3 Poisson's ratio

During the deformation at the bistable domain the strain tensor from Eq.6 becomes:

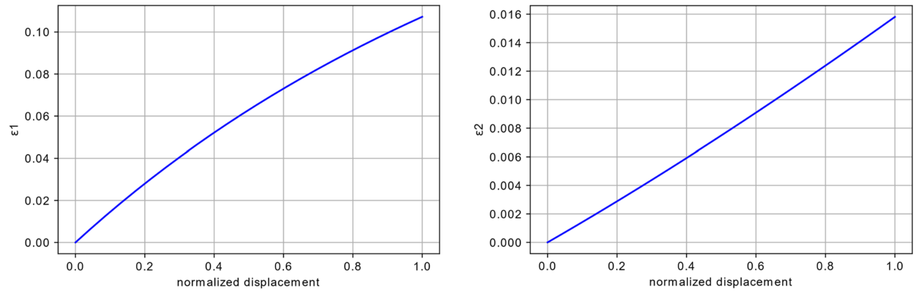

Fig. 7. Strain tenso

Therefore the function of Poisson's ratio is:

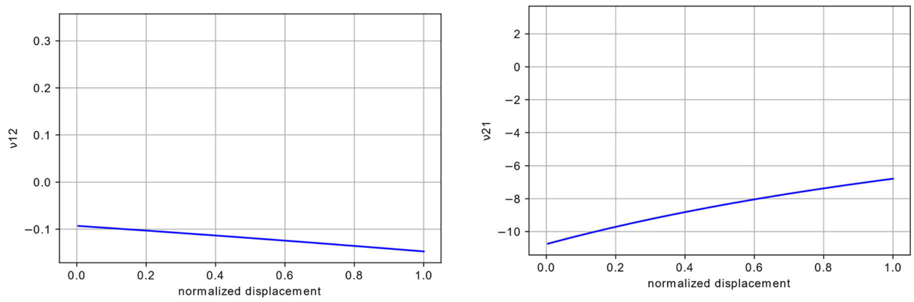

Fig. 8. Poisson's ratio

6.4 Deformation load

$$P_i = \frac{\frac{\partial U}{\partial \theta}}{\frac{\partial h_i(\theta)}{\partial \theta}} = \frac{k_l \Delta\psi \frac{\partial \psi}{\partial \theta}}{\frac{\partial h_i(\theta)}{\partial \theta}} \Rightarrow \left| \begin{array}{l} \dfrac{P_1}{k_l} = \dfrac{\Delta\psi \frac{\partial \psi}{\partial \theta}}{\frac{\partial(h_1(\theta))}{\partial \theta}} \\ \dfrac{P_2}{k_l} = \dfrac{\Delta\psi \frac{\partial \psi}{\partial \theta}}{\frac{\partial(h_2(\theta))}{\partial \theta}} \end{array} \right. \tag{33}$$

The ratio of force by the stiffness of the linear spring as a function of normalized displacement is shown in the graph below (Fig.9). The force does not monotonically increase with displacement. The saw-tooth serrations are caused by snap-through buckling, from which the metamaterial bistability originates.

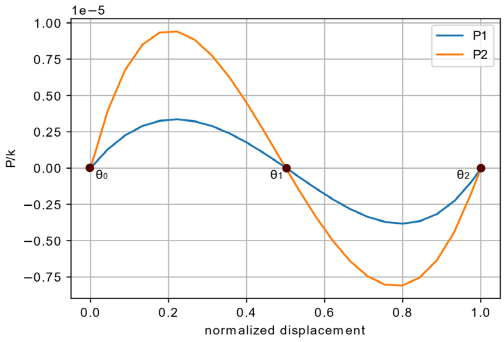

Fig. 9. Deformation load.

6.5 Relative density

From Eq. 23 we get the bulk volume in the three equilibrium positions:

$$V(\theta_0) = 59.74mm^3 V(\theta_1) = 53.71mm^3 V(\theta_2) = 45.45mm^3 \tag{34}$$

So, the relative density fraction in our two stable states is:

$$\frac{\rho(\theta_2)}{\rho(\theta_0)} = \frac{V(\theta_0)}{V(\theta_2)} = 1.31 \tag{35}$$

6.6 Stiffness

The stiffness is negative between the maximum and minimum points of force.

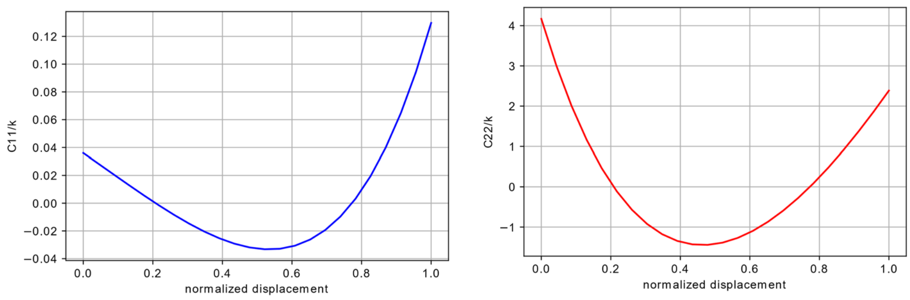

Fig. 10. Stiffness tensor

7 Conclusions

In this paper, we presented a novel planar mechanical metamaterial that exhibits bi-stable and auxetic behaviour. The combined structural bistability and negative Poisson's ratio has not been previously observed in the re-entrant arrowhead topology. We believe the proposed mechanism enable the design of new programmable structures across scales and the reduction of energy consumption in various sectors.

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Historic building and green energy: Strategies to make supply from renewable sources compatible with conservation

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Abstract. The challenges of today are largely summarized in the United Nations 2030 Agenda. Buildings are also part of the 17 sustainability goals in several respects, one of them being the role of reducing greenhouse gas emissions, reducing waste, assessing the life cycle of materials, limiting heat loss and introducing renewable energy sources. In particular, the contribution deals with how to ensure the supply of energy from renewable sources for cultural assets and buildings that are part of historic centers. In these cases, it can be very difficult to achieve both the objective of protecting the monument or landscape as well as that of installing or connecting the building or urban or rural settlement to renewable energy sources. Through some European and Italian examples in particular, where about 8 million buildings were constructed before 1945, about 25% of the total, virtuous ways will be presented that make it possible to achieve both objectives simultaneously. The regulations that favor this dual objective will also be highlighted, such as the one of the Veneto Region on so-called energy communities and the national one that allows the deferral of energy production from one place of cultural interest to another that has none, without serious costs for the final beneficiary and safeguarding the cultural asset.

Keywords: Cultural Heritage, Climate Change, Green energy

List of abbreviations and acronyms

SDGs, *Sustainable Development Goals*

ICOMOS, *International Council on Monuments and Sites*

CE Delft, *Catalysis Engineering (Delft University of Technology)*

ENEA, *National Agency for New Technologies, Energy and Sustainable Economic Development*

PNRR, *National Recovery and Resilience Plan*

PNIEC, *National Integrated Energy and Climate Plan*

APE, *Energy Performance Certificates*

BIPV, *Building Integrated Photovoltaic systems*
BAPV, *Building Applied Photovoltaic*
D. Lgs., *Legislative decree*
CoP, United Nations - Climate Change - *Conference of the Parties*
COM, *referred to European Commission*
EU, *European Union*
MW, *Megawatt*
TWh, *Terawatt-hours*
GWh, *Gigawatt hours*
RES, *Renewable energy source*
IPPC, *Intergovernmental Panel on Climate Change*
MtCO2eq, *Million Tonnes of carbon dioxide equivalent*
Mtoe, *Million tonnes of oil equivalent*
EURAC, *private research center based in Bolzano*
SUPSI, *University School of Italian Switzerland*

1 Introduction

After the Millennium Summit in 2000, the first sustainable development goals (Millennium Development Goals) were introduced. These were the basis for the adoption of global policies and measures, while also the first commitments of states to achieve sustainable development goals were defined. Since then, the green transition has not only served to improve the quality of the environment, but has also become «a new paradigm aimed at reducing the risks associated with global threats such as climate change, loss of biodiversity, desertification, and depletion of natural resources, while at the same time enhancing social and economic well-being» [1,2].

2015 was the year of the *Sustainable Development Goals* document, better known as *Agenda 2030* and shared by 193 countries of the *United Nations*, containing universal goals, to be achieved by 2030, consisting of 17 SDGs and their 169 targets, the result of integrating the elements of environment, economy and society. Many of these objectives are relevant to the principles of heritage conservation, with the aim of limiting the use and waste of resources and land. As far as energy is concerned, in the logic of the ecological transition, the supply of energy efficient renewable energy sources plays a decisive role, an area in which buildings are important, requiring attention with respect to plant evolution and with respect to the technologies offered by the market in the field of renewable energy.

In the face of such significant and global goals, a certain capacity to ground measures and policies is needed because «localizing the SDGs means much more than 'landing' internationally agreed goals at the local level. It means making the aspirations of the SDGs a reality for communities, families and individuals, particularly those at risk of being left behind. Local governments are crucial in the process of transforming the *2030 Agenda* from a global vision to a local reality. And local communities, stakeholders who know best about individual and collective needs and capacities, are key partners in the implementation and delivery of the global agreement» [3]. 2015 is also the year of the *Paris Climate Agreement*, which calls for the countries involved to respect the temperature increase by 2100 to a maximum of 1.5-2 C°. First among all continents, the European Union is devoting many measures and resources to the theme of improving the quality of architecture, initiating processes of redevelopment and efficiency of the building stock, reducing pollution and land consumption, priority objectives that can be traced back to the *New European Bauhaus* and *Green Deal*.

2 Energy and European Historic Buildings: Present Situation and Perspectives

2.1 The 2030 Agenda and the Europa Nostra and ICOMOS cultural role

In Europe, about 30% of buildings can be considered historic. Of these, between 2% and 5% in the different states [4] are buildings with specific levels of protection of cultural origin. The global goals signed in the *Paris Agreement* - in the different global COPs and those contained in the *2030 Agenda*, as well as the related European goals set out in the *Green New Deal* aiming at decarbonization and reduction of global warming gas emissions and the goal of zero land consumption in 2050 - require each country to move in a coordinated way with the others and with a certain urgency to implement appropriate measures. It is noted that the role of Cultural Heritage is considered not only part of the problem but also of particular significance.

The Green Paper on European Cultural Heritage (2021, Europa Nostra, ICOMOS, Climate Heritage Network) «argues convincingly that our cultural and natural heritage is fundamental to realizing the ambitions of the European Green Deal [...]. The rich and diverse landscape of our continent is also deeply intertwined with cultural heritage, being tangible or intangible, urban or rural, inland or coastal. Climate change, consequently, affects both people and their living and working environments. [...] But cultural heritage is also part of the solution» [5].

The 2019 ICOMOS document entitled *The Future of your Pasts: Engaging Cultural Heritage* also addresses the issue of climate change in relation to cultural heritage and the new associated risks. According to ICOMOS, climate change exacerbates risks and threats, and therefore determines the urgency of improving good conservation practices.

Cultural heritage can play a decisive role for the challenges of this era as «cultural factors determine the enabling conditions for adaptation and mitigation, including whether and how people respond to calls for climate action. Recognition at the highest political levels of the role of cultural heritage, together with the urgency of the challenges of climate change, creates a profound opportunity and a challenging responsibility for all those connected with heritage» [6].

In Europe, on average, buildings account for 40% of energy consumption and 36% of the emission of greenhouse gases. With the *Fit for 55* package [7], the European

Union aims to reduce harmful emissions by 55% by 2030 compared to 1990 levels. A building in the lowest energy class consumes 10 times as much energy as a zero-emission building: the aim is to encourage member states to make buildings more comfortable, more efficient, reducing the use of fossil fuels, combating energy poverty and polluted air, both at building and city scale.

2.2 The European directives on buildings energy efficiency

Since 2010, a series of directives concerning the energy efficiency of buildings have been disseminated. In 2021, with communication COM (2021) 802 - final [15], a significant proposal was presented to improve the EU 31:2010 Energy Efficiency Directive [16], already amended by Directive 844:2018 [17] and Directive 786:2019 [18].

The final draft, after a lengthy discussion and a considerable number of amendments, is awaiting consideration by the European Parliament and European Council for final approval. The proposal for new directives on the energy efficiency of the built heritage is intended to align the rules for the energy performance of buildings with the Green Deal and give the necessary impetus to complete the process of decarbonizing the building stock by 2050. What had emerged from previous evaluations [4] about the possibility that listed historic buildings would no longer be exempted, in the form of a derogation, due to their characteristics and represented value, seems to be definitively overcome.

However, the reliability of energy performance certifications and the consideration of interventions for their overall environmental impact are still issues under discussion, even though the energy performance certifications of buildings will have to report the relevant life cycle emissions and a green license will be introduced. The December 2022 proposal exempted from the obligation of energy efficiency policies historic buildings - to be identified by each state - places of worship, temporary buildings with a time of use of less than two years, industrial sites, workshops, and non-residential agricultural buildings with low energy demand; residential buildings that are used or intended to be used less than four months a year or with energy consumption of less than 25% of the estimated annual consumption - so-called holiday homes - and finally detached buildings with a total covered useful floor area of less than 50 square meters. With regard to the target, the new proposal is more restrictive than that of December 2021, which envisaged the transition from energy class G to at least F, by 2027 for non-residential buildings and by 2030 for residential buildings, but allowing a longer period for the transition. The first step concerns new buildings, which must be zero emissions ones by 2030, a target to be brought forward by two years for public buildings. In general, new buildings must reduce energy requirements and at the same time be powered as much as possible by renewable energy sources.

New minimum energy performance standards are proposed, starting with a share of each Member State's building stock with the worst energy performance, which will have to rise progressively by one or more classes, starting in 2027 and 2030, in order to reach zero emissions by 2050, fulfilling the requirement to alleviate energy poverty and achieve targets for drastic reductions in greenhouse gas emissions. It is noted the introduction of minimum energy performance standards, based on the behavior of each state with respect to energy efficiency and decarbonization targets, also defined as a national target of progressive decrease of the average primary energy consumption of the entire building stock in the period 2025-2050, aimed at achieving the important goal of zero emissions by 2050. For existing buildings, the directive aims to introduce minimum energy performance standards corresponding to the maximum amount of primary energy that buildings may use per m² per year [9].

Two very significant conclusions derive from this set of efficiency standards:

- the first is that all national ecological transition plans will have to be fully integrated into energy and climate plans, because these two issues are interconnected;
- the second is that to achieve certain ambitious decarbonization targets by 2050, the European Community and the member states will have to develop a powerful policy of economic subsidies: according to estimates, the transition from the lowest class to class F will affect about 30 million out of more than 210 million buildings in Europe, and up to 150 billion Euro will be allocated for the implementation of minimum energy performance measures until 2030 to facilitate the transition.

2.3 Are we moving towards new ways of using energy?

Besides the topic of energy efficiency, the technological evolution of renewables is also a central issue with respect to the environmental sustainability goals. According to an Italian study [8], today the independence of citizens is assuming an increasingly significant role in the context of the current energy supply dynamics, which the crisis of fossil fuels on the one hand, and the increase in prices due to the geopolitical context on the other, has made an important issue. European governance seems to favor these dynamics, allowing more control over energy choices, which is likely to lead to a truly revolutionary reform of the energy market within a few years. The study states that «according to a report published in 2017 by the Transnational Institute and the European Federation of Public Service Unions entitled *Return to public management of basic services: Municipalities and citizens close the privatization chapter* in recent years there have been at least 835 cases worldwide of a return to municipalized service of public utilities involving more than 1,600 cities in 45 countries» [8]. Among the most significant cases is that of Hamburg, Germany, where «a new public company (*Hamburg Enèrgie*) was established with the aim of building plants powered by renewable sources and marketing the energy produced. The initiative [...] resulted in the installation of more than 13,00 MW of wind power and 10,00 MW of photovoltaic power, involving local citizens and businesses as co-investors. In less than 10 years, *Hamburg Enérgie*'s customers have grown to over 100,000» [8].

Similar cases to Hamburg have also occurred in Spain, in particular in Barcelona, where thanks to the municipal company *Barcelona Energia*, the supply of renewable energy for 3,900 public consumers in 2018 was increased to 20,000 private consumers in 2019 at market prices throughout the metropolitan area [8]. The same study reports on the initiative of Nicola Sturgeon, Scotland's first minister, who in 2017 proposed the creation of a public company to provide 100% renewable electricity especially to low-income households.

The forms of citizen involvement in these open processes of the energy market are also different from those of municipalization processes, thanks to the impetus of market liberalization: «With the activation of the liberalization process and thus the opening up of energy production and sales activities to competition, other companies were allowed to enter the electricity system. And it is precisely the characteristics of renewable energies, which are extremely widespread throughout the territory, that suggest an alternative model for organizing the energy system and in particular the electricity system. A widespread system, where the consumer can also be a producer» [8]. The form that is most likely to favor these processes of diffusion of renewable energy users is undoubtedly the cooperative form, in which users join together in aggregated associations.

This has already happened in many European countries and represents a phenomenon of definite interest for the near future in Europe: «Denmark was in many ways a pioneer, hosting almost 1000 cooperatives in 2000. *Ecopower* is active in Flanders: established with 30 members in 1990, it now has more than 50,000 members who have invested more than 50 million EUR and provides electricity to more than 1% of Flemish households.

Som Energia was founded in Girona in 2010 and has 57,000 members and almost 100,000 contracts throughout Spain.

In Germany, cooperatives active in the energy market increased from 86 in 2006 to 1024 in 2016, including almost 200,000 members in total. Taken together, German energy cooperatives sell more than 80 TWh per year (or 15% of the German electricity market).

In a recent study by CE Delft (*The potential of energy citizens in the European Union*) it is estimated that by 2050 more than 250 million European citizens could contribute to producing the electricity they consume [...] and cooperatives could reach 16% of European electricity supply.

In Italy there are currently more than 30 cooperatives serving almost 50,000 consumers through 1,000 km of grid for a total of about 200 GWh per year» [8].

3 Some suggestions and good practices from Italy

3.1 Two measures: *façade bonus* and *ecobonus*

The Italian government has introduced forms of incentives for the realisation of interventions to improve the efficiency of the building stock, historical and protected buildings. There are essentially two measures: the so-called *façade bonus* and the *ecobonu*s. The *façade bonus* is a tax relief consisting of a tax deduction of 90% of the expenses incurred in 2020 and 2021, and 60% of the expenses incurred in 2022, for interventions aimed at recovering or restoring the external façade of existing buildings, of any cadastral category, including instrumental properties. The buildings must be located in historic centres. Only interventions on the opaque structures of the façade, on balconies or on ornaments and friezes are eligible for the benefit, including those only for external cleaning or painting. On the other hand, the bonus does not apply to work carried out on the building's internal facades if they are not visible from the street or from ground for public use. The measure aims to combine objectives of decorum with those of efficiency, except in the case of building envelopes that are not suitable for this dual purpose.

The *Ecobonus* - also known as *superbonus* - is the tax relief introduced in 2020 that consists of a 110% deduction of the expenses incurred from 1 July 2020 for the implementation of specific interventions aimed at energy efficiency and static consolidation or reduction of the seismic risk of buildings. Facilitated interventions also include the installation of photovoltaic systems and infrastructure for recharging electric vehicles in buildings. The main objective is to achieve energy efficiency in buildings, without neglecting other objectives. To obtain the tax benefit, the interventions must lead to a jump of two energy classes.

To date, the measures have cost the Italian state over 68.7 billion EUR for a total of over 359,000 buildings [19], just over 2% of the Italian building stock. It will be necessary to take more analysis in the future, but it already seems clear that the number of buildings that have benefited from the *ecobonus* measure, now relaunched with a lower tax benefit quota, is very small compared to the total and, on non-listed historical buildings in many cases, in the absence of specific sector regulations, it is common to carry out interventions that seriously alter their historical and documentary qualities.

3.2 The perspective of the National Recovery and Resilience Plan and other energy transition plans

The goal of the national PNRR (*National Recovery and Resilience Plan*) for the ecological transition involves a total investment of almost 70 billion EUR with the aim of reaching 30% renewable energy by 2030, increasing this to 70% by 2050. In addition to these operational measures, which have shaken up the market and put Italy in the position of having drawn up and applied a regulation that goes in the right direction, in the author's opinion, it is in line with the declared objective of the *European Green Deal* to «start a wave of renovations» of public and private buildings, a *National Integrated Energy and Climate Plan* (PNIEC) [10] that was drawn up and approved. Basically, the plan follows two points of European policy to drastically reduce pollutant emissions by 2030 and to achieve full decarbonization by 2050. Looking in detail at the individual sectors, the most significant contribution to CO2 emissions is made by transport and civil sectors (residential and tertiary), which account for 100 and 72 MtCO2eq respectively by 2020 out of a total of 278. The Plan interfaces with other actions and envisages a strategy characterized by multiple measures to achieve certain targets. On the one hand, limiting our considerations to the civil built heritage sector, «the reduction in emissions to 2030 compared to 2005, in the PNIEC scenario is around 35 MtCO2eq and reflects the expected acceleration in the rate of energy efficiency of existing buildings, reinforced by a greater diffusion of deep redevelopment interventions and the application of particularly high-performance technologies» [10]. Also, at national level, the binding European target of at least 32% of energy from renewable sources in 2030 will have to be pursued in order to facilitate the implementation of the energy mix that will progressively move away from fossil fuels according to the following contributions: «55% share of renewables in the electricity sector; 33.9% share of renewables in the heat sector (heating and cooling uses); 22% incorporation of renewables in transport» [10]. With reference to the electricity sector, in addition to other sources for which limited growth is expected, such as geothermal and hydropower, in order to direct the deployment of the significant incremental capacity of photovoltaics envisaged for 2030, the «Plan envisages promoting their installation primarily on buildings, canopies, car parks, service areas, etc.'. However, it remains important for the achievement of the 2030 targets that large ground-mounted photovoltaic systems also be deployed, but giving priority to unproductive areas, not intended for other uses, such as areas that cannot be used for agricultural purposes. In this perspective, realizations in already artificial areas [...], contaminated sites, landfills and areas along the infrastructure system should be favored» [10]. With reference to the heating sector, the intention is also to encourage the spread of heat pumps, which, «given their high efficiency, will have an increasing weight in the renewable thermal mix, further supported by technological progress in the sector»[10]. Furthermore, again according to the PNIEC, «an increase in the share of thermal RES will also be achieved through widespread redevelopment of the existing building stock leading to a significant reduction in consumption» [10]. As also shown by the trend reported in the latest IPCC report, with reference to the year 2017 - the first useful year in which the PNIEC was drawn up-, energy consumption marks the strong incidence of the civil use sector, 45% of total final consumption, up by 7.4% compared to 2016. Of this 45%, 29% of the total is absorbed by the residential sector, while 16% is absorbed by the service sector, which is the one with the highest growth. As is well known, in order to achieve the binding national target of decarbonization and the introduction of adequate RES quotas for both the electrical and thermal sectors, the main instruments in the field to promote the use of thermal renewables are often integrated with those for energy efficiency and are already operational, and a considerable share of these resources are allocated to the measure of tax deductions for energy efficiency measures and the building renovation of existing building stock. According to the PNIEC it is estimated that «as a result of the measures in force today by 2030 it will be possible to achieve annual energy savings from building redevelopment of 5.7 Mtoe, of which 3.3 Mtoe from the residential sector and 2.4 Mtoe from the tertiary sector (public and private)» far greater than that expected from the industry sector (1.3 Mtoe) and the transport sector (2.6 Mtoe), which confirms the significant role in achieving the de-carbonization and energy efficiency objectives represented by the building stock. Although the potential for energy savings in the civil sector is very large and can often be attributed to energy efficiency measures with sustainable payback periods, a great deal of effort is required to overcome congenital difficulties in the processes and in the various fields of application.

It is interesting to note that the PNIEC identifies - in addition to the need to strengthen minimum standards and regulations and the related checks and controls - the introduction of measures to improve the quality of Energy Performance Certificates (APE) and ways to encourage the purchase of high energy class homes, strategic objectives such as «improving the compatibility between energy efficiency objectives and the use of renewable energy sources in buildings, the possibility of introducing energy efficiency obligations during renovations, justified in terms of cost-benefit ratio, and the promotion of synergies with renewables in self-consumption» [10].

3.3 Can the "energy community" and the "on-site exchange elsewhere" radically change the ways of energy supply?

As well explained by the Veneto Region architect Franco Alberti in a conference promoted by the University IUAV of Venice, «the energy community is based on the decentralization of energy production» [11], favoring the sharing «in energy communities of citizens, associations and business entities, which share a set of principles and rules and procedures concerning the management and governance of the community, towards self-management and sharing of resources. End customers, consumers of electricity, can join together to produce locally, through renewable sources, the electricity necessary for their own needs» [11]. A 2022 law of the Veneto Region promotes energy communities and sets a series of goals in line with some European best practices and the guidelines of the national PNIEC, responding to the current energy crisis by setting the following series of goals:

- promotion of local development in terms of competitiveness, environmental sustainability and circular economy;
- contribution to the achievement of energy autonomy and sustainable energy transition as well as to the fight against energy poverty;
- innovative energy supply, distribution and consumption model to facilitate the production and exchange of renewable energy, energy efficiency and reduction of energy consumption [12].

«After about a year of experimentation», Alberti continues, «now this decree introduces important new features in the field: plants will be able to reach a higher maximum output and communities will be able to relate to much larger territorial portions, encouraging greater investment and benefits for users. We are therefore moving towards a greater dimension of energy communities, given their role both in the ecological transition and in achieving the climate and energy objectives of the coming decades: consider that ENEA predicts that in 2050 there will be 264 million prosumers, who will produce up to 45% of the EU's renewable electricity» [11].

Another measure that may be very important in the future to encourage a widespread diffusion of energy from renewable sources, without necessarily equipping historic buildings with such installations while safeguarding their characteristics, is the so-called on-site exchange elsewhere, whereby users can feed excess photovoltaic energy produced into the electricity grid and then withdraw it at a later date, without the need for the feed-in and withdrawal points to coincide.

3.4 Integrated photovoltaics as an innovative technology for energy efficiency in cultural heritage

A recent document called *Guidelines for the Integration of Photovoltaics in settings of historic and scenic value* [13] aims to provide suggestions for the design and installation of integrated photovoltaic systems in contexts protected by Italian standard of protection of cultural property (D. Lgs 22/01/2004, n. 42) in the Lombardy Region. The paper was produced within the framework of the *Interreg 2019-2022 research project IT-CH - BIPV MEETS HISTORY - Creation of a new value chain for architecturally integrated photovoltaics in the energy rehabilitation of the historical built heritage*. The project was carried out by EURAC Research, the University School of Italian Switzerland - SUPSI and the Lombardy Region.

The approach and methodology used led to particularly innovative outcomes with respect to the issue of the provision of energy supply systems from renewable sources in areas of historical buildings and landscapes endowed with artistic and historical values, in a cross-border territory located between Italy and Switzerland.

In particular, the study highlighted the significant prospects for the use of BIPV (Building Integrated Photovoltaic) systems, building-integrated photovoltaic technology, which go beyond the logic of traditional BAPV (Building Applied Photovoltaic) systems, which are in fact plant systems that are installed or placed on existing elements, but are components of the building envelope such as roofs, appendages such as canopies and canopies, shading systems, parapets, curtain walls, etc.

Given today's standards and technologies, BIPV is the «technology that is most easily applied in historical and landscape restoration projects» [13]. Among the elements to be paid attention to, is in particular the need to carry out an integrated design and to define a balance between aesthetic, technological and energy aspects: «photovoltaic systems must be given an architectural value so that their insertion, especially on the historical-architectural heritage, is designed in an integrated way, also from a compositional point of view» [13]. In addition, «a site-specific assessment for each intervention remains essential, which takes into account and organizes the constructional, material, chromatic and compositional characteristics of the building, the broader landscape context in which it is inserted and the technological and plant engineering aspects of photovoltaics» [13].

It is also considered to highlight the Italian Decree Law 17/2022: the rule was drafted to respond to the challenge of energy transition and decarbonization, as well as the increase in electricity and gas prices. It provides for the introduction of measures to simplify and incentivize the installation of renewable energy systems, with specific reference to solar energy, both thermal and photovoltaic.

The law made some changes to the regulation to allow its application also in historical centers, with the exception of areas subject to landscape constraints, where prior authorization is still required, being understood that even for buildings located in constrained historical centers, installation is free if it is done with «panels integrated in roofs that are not visible from external public spaces and panoramic viewpoints, except for roofs whose coverings are made of traditional local materials».

4 Conclusions

The international scenario calls for stringent measures to reduce greenhouse gas emissions from the building sector, which alone accounts for about 40% of the total emissions. In Europe, a large part of the building stock is represented by historic buildings, some of which are also listed, in very small percentages.

If these buildings can be excluded from the application of the relevant efficiency directives, about 20-25% of the total buildings on the continent, to what extent will they be affected by the ecological transition? The green energy supply component is substantial, firstly because it is necessary along with insulation to increase energy efficiency and also because it serves to reduce the carbon emissions that are produced by traditional domestic systems. All European states, including Italy, are trying to work out measures to make this transition, which will possibly require substantial resources. The ability to build streamlined regulatory measures will be useful, resorting to energy supply systems different from the traditional ones, which favor communities and the dislocation of the place of production from that of consumption. Likewise, the results of technological innovation will be very important.

In conclusion to this short series of reasoned information, we share what has appeared in an Italian newspaper in 2021 [14]: one of Italy's leading cultural heritage experts, Salvatore Settis, warns that we must soon move from an abstract opinion on renewable energies to the concrete exercise of substantive choices, also pointing out that wind and photovoltaic plants can also have a negative impact on the historical landscape. The expert rightly points out that the issue can lead to a choice between two mutually relevant instances such as landscape protection and ecological transition, and that a balance is needed so that one does not override the other [14].

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The Hellenic landscape and renewable energy sources: A social survey (2022) and some considerations

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Abstract. The aim of this paper is to underline the urgent need for the further penetration of renewable energy sources in Greece and the consideration of related problems regarding the natural environment, the archaeological sites, the traditional architecture, and the existing contemporary urban environment. Some references to the theoretical approaches of the subject of environmental Aesthetics are also mentioned. The method to achieve conclusions has been a social survey of the opinions of Greek people, regarding their surrounding environment and the application of renewable energy sources. Concluding, the economic factor proves to be very important, primarily at the individual level and then at the social or national level, while the aesthetic factor seems to follow the economic one, being also very important.

Keywords: environmental aesthetics, environmental psychology, Survey, renewable energy sources, environment

1 Introduction

It is known that Plato was the first in "Kritias" to complain about the alteration of the natural landscape of Athens both by intense natural phenomena, and –especially – by the human activity of logging for building purposes: "…χρόνος δ'ου πάμπολυς, ό'τε δένδρων αυτόθενεις οικοδομήσεις τας μεγίστας τμηθέντων στεγάσματα..", op.cit., III D (… it has not been a long time, since trees around Athens have vanished, in order to construct the roofs…). And at the same time he mentions the climate change: "… γην δε άριστην και ύδωρ αφθονώτατον εχόντων, και υπέρ της γης ώρας μετριώτατα κεκραμένας…", op.cit., III E (before sometime, the land was excellent, we had plenty of water, and the weather was better…).

The problem of intervention and alteration of the natural landscape by man is not new, nor even particularly recent. From the Pyramids to Mexcaltitan and from Cappadocia to the Amazon forests, man has always intervened in the natural landscape, even invoking the idea of "Monument" or "human needs". The problem has of course grown since the so-called "industrial revolution". The needs for both energy and concentrations of workers and consumers, have led to the current state and situation. Factories, dams, pipelines, power stations and transport networks, transport axes, quarries and logging, and of course cities and towns, strongly demonstrate the alteration of the natural environment.

Nevertheless, energy needs are constantly increasing, resulting in the depletion of natural resources and the increase of pollution. The need for a shift to renewable and non-polluting energy sources has been emphasized since 1973 (first oil crisis and "The Limits to Growth" [11]. In Greece, we are dealing with natural gas and lignite while Rifkin [15] during an interview has stated that "…your country with so much sunshine and so many winds, I do not understand how it is not energy independent...".

1.1 The background

Several famous Greek architects have mentioned the destruction of the Greek landscape by human interventions. Dimitris Pikionis with "Γαίας ατίμωσις" (The disgrace of earth [13]), "The meaning of each building lays(for Pikionis) in absolute relation to the earth's surface, and as soon as the earth suffers anything, the meaning is erased from the buildings, or else, his architecture was distorted" (Lorentzatos[10]). And Pikionis says: "But the needs? You will ask me. Those who ask the question know very well that it is not the absolute necessity, per se, that is the cause of the disaster.", (Gaias Atimosis, op.cit). And also Aris Konstantinidis [6] blasts those who "... They want to impose themselves 'artistically' with ostentatious constructions, in order to amaze a consumers' society that seeks, unthinkingly, any stimuli to overcome its boredom, as well as its illiteracy and lack of any intellectual culture."

The references cited are based on our classical education for beauty. Aristotle had already stated in his "Rhetoric": "Καλόν εστίν, ο αν δι αυτό αιρετόν όν επαινετόν ή" (it is good, if it is per se elected and admired) and "ο αν αγαθόνον ηδύ η ότι αγαθόν" (nice is that which, by being good, is pleasant) and in the "Meta ta physica", he mentions the elements of beauty: "τάξις, συμμετρία, ορισμένον, πεπερασμένον" (order, symmetry, defined, finite). Thomas Aquinatus redefined later the determination of aesthetically good as wholeness, harmony and clarity (integritas, consonantia, claritas , in "de veritate").

Of course, as J. Joyce [5] points out "fire is good as it warms us up. When it burns us, it's hell". And that helps us wean ourselves off the "pulchra sunt quae visa placent" (St. Thomas, op. cit.), and helps us to relate to usability, to satisfy human needs... Let's also remember Vitruvius who emphasized the concept of Utilitas (utility) along with firmitas (solidity) and venustas (beauty).

Moving on to P. Michelis [12] we find that: "Modern Greek society is far from nature and in contrast to it. It tries to tame it first with technical works, bridges, roads, etc., which will later only allow it to overcome what is practically necessary and glorify ... the "kitsch". However, always seeking the problem of the relationship between utilitarian necessity and aesthetics, we must cite the predicate of Arnold Berleant [3]: "We cannot, in valuing the environment, refer to an object... The usual tactic of contemplative admiration must be replaced by the interactive relationship that entails evaluation".

The approaches to the relationships and interactions between man and the space that surrounds him, apart from our classical education, about which just a little has been mentioned above, are covered analytically by phenomenology, semiotics, deconstruction and in particular by Environmental Psychology, that has left the study of personal aspects in vitro, and studied them in situ, in the everyday surrounding environment (cf. Kosmopoulos, 2000).

1.2 The current situation

The problem of positions and attitudes towards the new morphological imperatives of the applications of RES in our country is already appearing and will become more acute with the need to expand these applications because of the recent energy crisis. Photovoltaics in Zagorochoria and Mystras? Wind turbines on the Acropolis and Lycabettus Hill? Traditional settlements, listed buildings, proximity with archaeological sites, natural areas of particular beauty, will definitely trouble us. Personally, it has been a shock when, many years ago, we saw in a village in Austria the bell tower of a church dressed in photovoltaics. How will the modern Greek react? People need electricity in Delphi, but they do not accept to see The Phedriades covered by photovoltaics and wind turbines. On the one hand, the need for independence from imported energy, for economic benefits, for minimization of ecological destruction. On the other hand, the need for morphological intervention. And at the same time, the major economic interests and the micropolitical local businessmen and politicians, who all these, through the dominant media, intervene, influence and determine, Attitudes and Perceptions towards the problems, shaping the “Public Opinion”.

2 Method

Before the legislation of the new measures for the expansion of the applications of RES, we completed a survey at a national level on the public's attitudes on this issue (October 2022 – January 2023, 987 questionnaires). The research aimed both at investigating the public's awareness of RES, and -in particular- at attitudes towards morphological interventions at the landscape.

2.1 The Survey results

We present below some important points from the survey:
Sex: Male53.32%, Female46.68%
Age groups: 18-25→6.92%, 26-40→31.28%, 41-60→32.49%, 61 and above→29.31%
Educational level: Compulsory Education→0.80%, Lyceum→1.20%, College→22.65%, University degree→41.11%, Master-Ph.D. →34.24%

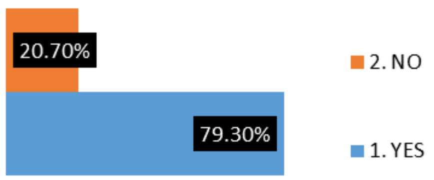

Fig. 1. Do you know that our country depends greatly on imported fuels (oil and gas) in order to have energy?

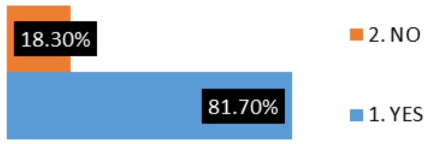

Fig. 2. Do you know that photovoltaics and wind turbines produce electricity, do not pollute the environment and do not depend on imported fuels (oil and gas)?

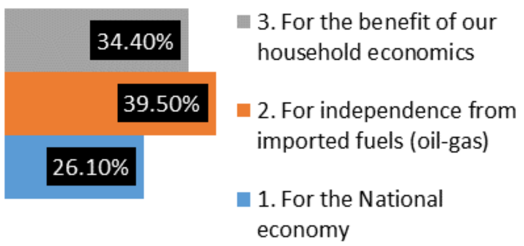

Fig. 3. Do you think that in our country large scale photovoltaic parks and wind turbine parks have to be installed? IF YES

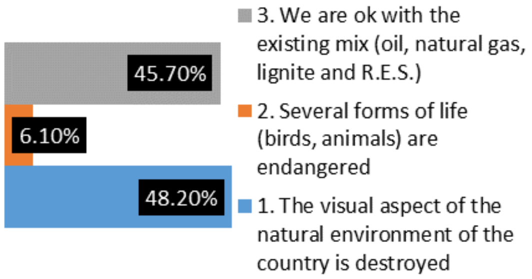

Fig. 4. Do you think that in our country large scale photovoltaic parks and wind turbine parks have to be installed? IF NO:

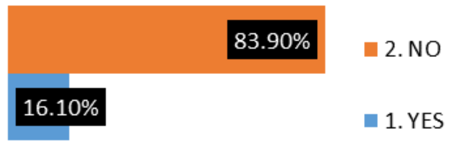

Fig. 5. Do you think that large scale installations of PV parks and WT parks negatively affect or destroy the aesthetics of the natural environment and/or of the buildings?

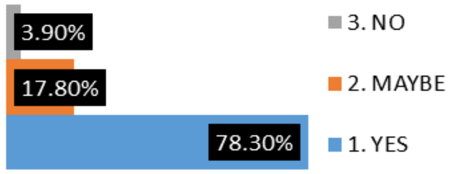

Fig. 6. RES installations should be placed away from agglomerations, tourist attractions and protected natural areas.

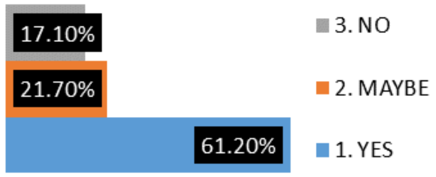

Fig. 7. Do you think that turning to RES (photovoltaics, wind turbines etc.) and the independence from oil/gas/lignite will reduce extreme weather phenomena attributed to the climate change?

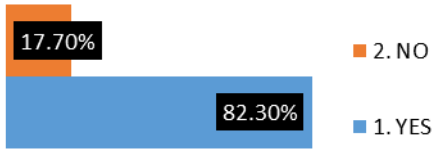

Fig. 8. Do you think that photovoltaics and wind turbines have to be applied at your house (either existing or under construction)?

Fig. 8.1. IF YES, what is the reason?

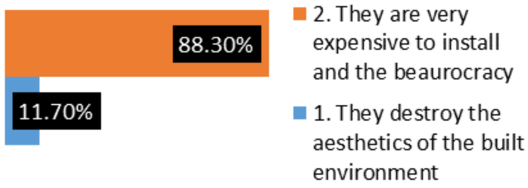

Fig. 8.2. IF NO, what is the reason?

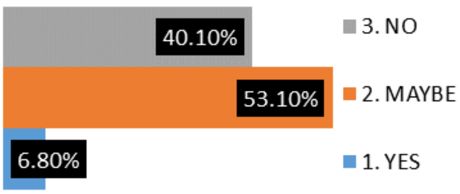

Fig. 9. Do you think that the possible exploitation of fossil fuels in our country (sea, land) will harm the natural environment?

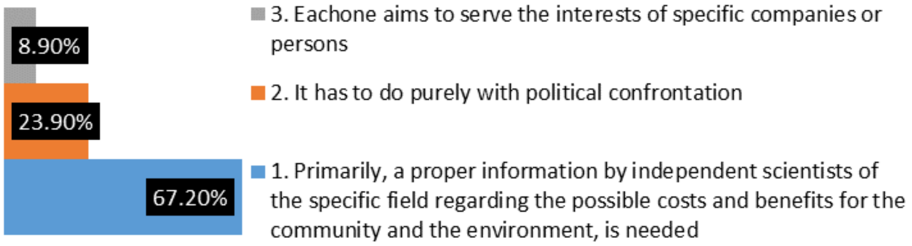

Fig. 10. What do you think about the usual disputes regarding the location of the installation of large-scale projects of RES between each central government and the local authorities, communities and/or any opposition parties?

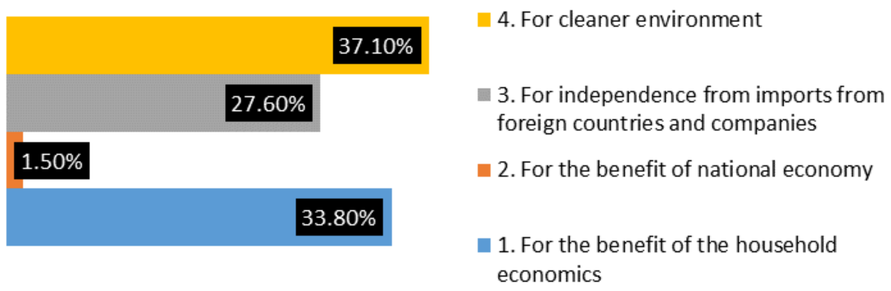

Fig. 11. Finally, the reason you wish the installation of RES is:

The answers of the participants offer a clear and very interesting view of how nowadays Greek people face the subject of the RES application at both small and larger scale, especially after the recent and urgently needed independence from traditional energy sources.

Relative researches on this subject have been carried out by our team and Laboratory, during the past years, long before the almost obligatory implication of RES in our country. Recently the legal framework regarding RES changes from month to month, according to the international and European conditions. It is obvious that the opinions of the people have changed over the last years. It has also been emphasized by the respondents (67.20%) the need for proper information by independent scientists about the costs and benefits of the installation of RES applications.

3 Conclusions

1) It turns out that there is a satisfactory level of public information, which is mainly attributed to the media (television, social media, newspapers, magazines, radio).The economic factor proves to be very important, primarily at the individual level and then at the social or national level.
2) The aesthetic factor seems in principle to follow the economic one, but without being indifferent.
3) At the building level, there is concern about the integration of new elements into the already existing/given forms of the shells. Problems will certainly be encountered in traditional buildings, settlements, and proximity with archaeological sites. In the case of new buildings, the integration of RES seems to be easier.
4) At the suburban and rural environment, due to the size of the required facilities, the problems are more complex. The need for RES is acceptable, but fears are expressed about the alteration of the landscape. Especially emphasized is the NIMBY syndrome (not in my backyard): “to exist but not to see them”.
5) Also, on a general level, it turns out that the immediate economic benefits can bend some aesthetic concerns.

6) It turns out that the modern "social aesthetic perception", in addition to the ways of its affection, will have to face with "utilitarian" concerns and satisfaction of needs, both domestic and national.

4 Remarks

There is a possibility of dealing with problems similar to the sites of waste disposal fields, which for 30 years have been proposed and transferred from place to place. There is a conflict of aesthetic tradition habit with the new morphological imperatives, which overlaps with economic and environmental benefits (sudden revelation: identification of the two factors; the beneficial and the useful).It is good to remind us of the saying of L. Sullivan [16] "Form Follows Function", at least as far as building envelopes are concerned. Let's not forget, of course, that Socrates was the first to underline that his ugly nose is "nice" because it absorbs the air better...

The absolute need for Study and Design arises for proper integration of the RES into the landscape (either natural or man-made) to prevent destruction or degradation of the environment.

We believe that remembering in combination the basic positions and views on the aesthetics of space and the environment, mentioned in the first part, can lead us in the best possible way to shape the needs of the modern built environment. In conclusion, during the phase of planning of the installation of RES, it is good to remember Aristotle (op. cit.) who, between Lack and Exaggeration, emphasized the need for the Golden Mean or Medium, as well as Umberto Eco [4] who in his commentaries on the aesthetics of Thomas Aquinatus states that "The Aesthetic property of the artificial form is a consequence of its ontological reality and is not its primary purpose".

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Climate-Responsive Opportunities and Challenges in Urban Vernacular Heritage

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Abstract. In response to today's contemporary challenge regarding how to tackle the effects of climate change in heritage environments, natural ventilation arises as a compatible, low-cost and environmentally friendly passive cooling strategy for the Mediterranean climate. However, an identified research gap concerns the lack of studies addressing data from both the urban and building scales. An innovative, multi-scale approach is introduced in this research, through the study of airflow on the neighbourhood, street canyon and building scales, which is then evaluated using field measurements. The effect of urban density and street-canyon geometry on indoor thermal comfort is discussed in the case of adobe buildings with pass-through spaces (*portico*), and timber projections with multiple openings (*sahnisi*). The originality of the presented research lies in the adopted multi-scale methodology. On the district level of study, analytical tools and urban-scale considerations in the development of vernacular buildings are discussed through the lens of environmental performance. Building ventilation is addressed as a function of in-street and rooftop airflow, demonstrating the airflow gradient across the scales under study. Furthermore, the impact of various window operation patterns is quantified, given the variability of the background wind and street geometry. The results indicate best practices for enhancing the cooling effect of natural ventilation, highlighting the role of occupant behaviour and night-time ventilation. Finally, key directions regarding conservation practices in urban contexts are discussed, bringing energy performance and comfort into cultural heritage studies.

Keywords: natural ventilation, thermal comfort, vernacular, urban canyon.

1 Introduction

Built vernacular heritage, as defined by the relevant International Council on Monuments and Sites (ICOMOS) Charter in 1999, refers to "*the traditional way by which communities house themselves*"[1]. Its importance lies not only in the singularity of each built artefact, but also expands to the context of urban and rural complexes. The benefits of having continuously inhabited and vibrant historic urban centres range from the intangible advantage that heritage has on society and cultural identity, to measurable economic and environmental benefits[2]. In this respect, accommodating contemporary standards of living and complying with thermal comfort requirements is a common challenge;especially in light of climate change and unprecedented transformations in the social and urban context of historic centres[3].

Placing urban morphology in the climate context of its environment plays a key role in the liveability and continuous use of urban heritage. Historic Urban Landscapes (HUL), especially in hot, arid climates around the Mediterranean, are characterised by narrow, winding streets and wide courtyards in a continuous building system[4]. The airflow and thermal characteristics at street canyon level determine the heat flux and air quality of the city, thus, playing a crucial role in the energy demand of buildings[5]. Building density creates rather ambivalent microclimatic conditions. Narrow and winding streets contribute to the decrease of solar radiation and provide shading; however, they suffer from reduced cooling potential due to reduced outgoing long-wave radiation. Also, an increase in urban compactness entails a decrease of solar energy availability within the urban texture and an increase of heat island intensity in the urban area, especially at night. Thus, urban compactness may have contrasting outcomes in a building's energy performance, especially in the Mediterranean climate, where cooling and heating demand is equally significant[6].

Respectively, airflow within the urban canopy layer (UCL), which reaches the average building height, can be a far lower fraction of the free-stream wind speed that is developed at the top of the urban boundary layer (UBL). This has an impact on indoor ventilation and the provision of comfort ventilation, which is based on elevated air speed. Furthermore, air and heat exchange processes between the in-street and above-canopy region, define the ability of heat and pollutant removal, which in turn, define the boundary conditions for building ventilation[7]. The building density, as well as the degree of asymmetry and the variation of the building height are highlighted as beneficial in generating more turbulence at the top of the canyon, thus increasing the air exchange process between the air in the street canyon and the atmosphere. This capacity of an urban environment to 'ventilate' itself, termed as *breathability*, is often underestimated, as most numerical or laboratory studies focus on idealised geometries[8,9]. This highlights the need for further field studies in real urban settings and especially in historic urban centres with substantial heterogeneity that have been organically developed[10].

In turn, the built environment of the HUL incorporates several opportunities, as well as challenges, in terms of environmental performance. The climatic adaptability of vernacular buildings and settings has been confirmed by various studies highlighting the role of the building form and typology, the selection of building materials and the use of open and semi-open spaces[11–15]. However, several studies also address the potential of energy savings and emissions' reduction by retrofitting vernacular buildings[16–20]. Prior to exploring the potential of integrating innovative materials and renewable energy systems in a compatible way, it is imperative to cater for the protection and enhancement of the passive design strategies employed through the building envelope and its surroundings[21]. Particularly in the Mediterranean climate, natural ventilation emerges as a significant passive cooling strategy[22,23]. Especially in heavyweight buildings, night ventilation techniques are particularly effective in order to delay heat transmission and decrease the temperature amplitude of the outdoor environment[24–26]. As a non-invasive technique, natural ventilation constitutes a considerable advantage in the case of retrofit projects, given the delicate protective legislation schemes for heritage buildings. Also, this strategy has minimal operational costs and is considered an environmentally friendly alternative to relying on mechanical heating, ventilation, and air conditioning (HVAC) systems for comfort. Cross-ventilation and buoyancy-driven ventilation are enhanced by numerous building elements (e.g., pass-through semi-open spaces, courtyards, interior stairwells, windcatchers etc.), yet their effectiveness relies on both occupant behaviour and urban morphology[27,28]. The question that arises and has been investigated in this research, is the degree to which we can rely on natural ventilation as a cooling strategy in heavyweight vernacular buildings located in dense urban contexts.

2 Methodology

2.1 An overview of the research objectives, scales of study and tools

When it comes to the environmental assessment of vernacular heritage and the role of natural ventilation, an identified research gap concerns the lack of studies addressing data from both the urban and building scales. In this context, the research presented in this paper investigates the role of natural ventilation as a passive cooling strategy, to highlight the environmental challenges and opportunities that arise in urban vernacular heritage. One of the main research objectives and innovations of this research is to address building ventilation as a function of in-street and rooftop ventilation, as well as to decipher the role of urban geometry in determining any possible variation in indoor and urban ventilation. An innovative methodology is adopted for the consideration of the multi-scale nature of airflow on, a) neighbourhood, b) street canyon, and c) building scale, highlighting the airflow gradient across the different scales under study, in real field conditions. Analytical tools are employed on the district scale of study, which corresponds to the walled city of Nicosia, Cyprus. Respectively, environmental field monitoring is conducted in the selected neighbourhoods, street canyons and buildings (see

Fig.).

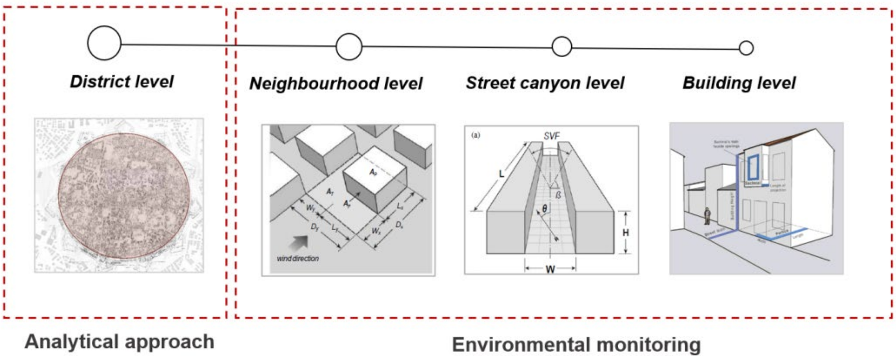

Fig. 1. Scales of study and main methodological tools employed.

An additional objective is to address the effect of various window operation patterns (applied by the occupants or under controlled conditions) on indoor thermal comfort. The focus is on heavyweight buildings with tripartite arrangement (*trimeres*), featuring two elements which both play key roles in natural ventilation[29]. The first is the pass-through space called *portico* that connects the street and the interior courtyard and the second is the timber projecting volume *sahnisi* (see Fig.). Furthermore, through this research, the role of the sahnisias a wind-capture element in a dense urban canopy is quantified under real field conditions.

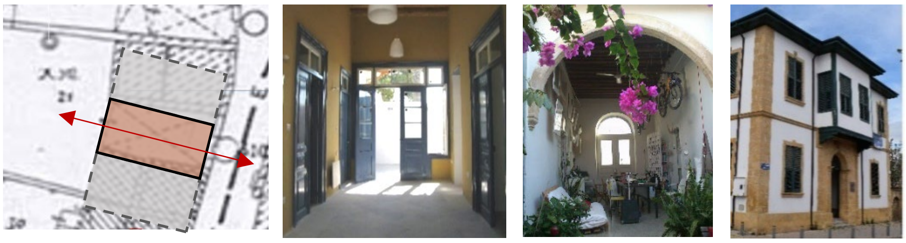

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Fig. 2. a) Typical tripartite arrangement of houses with portico (highlighted in colour); b) View of a pass-through portico space – towards the courtyard; c)A portico space in the original, semi-open form – view towards the street; d) Two-storey building with tripartite arrangement and sahnisi projecting volume on the first floor.

2.2 Analytical tools employed on the district scale of study

An analytical approach was adopted for the investigation on the district level of study. The aim was to identify the main typological and morphological features that play a key role in the effectiveness of natural ventilation on a building or urban scale. Additional goals were to investigate the interdependence of urban morphology and environmental parameters, such as insolation and ventilation. And finally, to select case study neighbourhoods, street canyons and buildings for further environmental monitoring. An innovative, multi-dimensional and multi-scale approach was applied to reading the historical process of defining the urban tissue and building typology. This was achieved through a holistic reinterpretation of historic, cultural and environmental factors, in order to interrelate these attributes to each other in a meaningful way. The tools used in this process involved historic references, maps, chronicles, in situ documentation and mapping of particular vernacular design elements in the wider district of the walled city of Nicosia.

2.3 Environmental monitoring on the neighbourhood, street canyon and building scales of study

Environmental measurements (focusing on temperature, relative humidity and air velocity) were conducted in, a) two neighbourhoods with distinctive building density, mean building height and street pattern; b) three street canyons with variable aspect ratio (two narrow canyons and one square shaped canyon); and c) three heavyweight adobe buildings with pass-through portico spaces (single-storey, double-storey and double-storey with sahnisi). Measurements were taken at the reference height of 2.5H, the mid-height and the top of the canyons, as well as in the portico spaces of the buildings. The cross-scale nature of ventilation is characterised through the normalised ratios of indoor velocity to canyon wind speed, U_{in}/U_c, as well as the ratio of canyon to reference wind speed, U_C/U_{ref}. Finally, the breathability capacity – which demonstrates the rate of air and heat exchange between the UCL and the RSL (laying above) – is quantified through the ratio of the non-dimensional exchange velocity, U_E, to reference wind speed, U_{ref}. A schematic representation of the cross-scale approach adopted in the environmental monitoring is presented in see Fig..

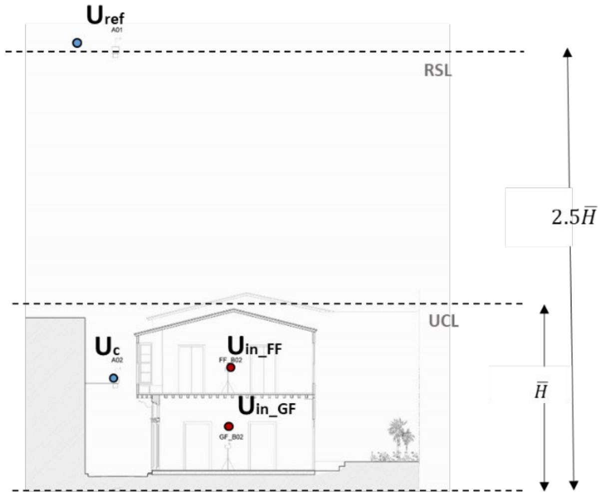

Fig. 3. Schematic representation of the cross-scale approach in the environmental monitoring.

Urban scale: A set of morphometric variables were adopted to describe urban morphology: the Sky View Factor (SVF), planar and frontal packing density (λp, λf) and mean building height. Area 1 is mainly comprised of two-storey buildings, whereas Area 2 is covered mainly by ground-floor residences with large courtyards, settled in a more organic and irregular street pattern. For this reason, Area 2 presents a higher SVF and a lower packing density than Area 1, i.e., SVF2=0.39±0.24, λp2=0.49, whereas SVF1=0.26±0.22 and λp1=0.60. Two narrow street canyons with aspect ratio H/W=2 (where H the building height and W the street width), located in Area 1 (i.e. Perikleous and P.P.Germanou str.), and one square cavity canyon (H/W=1) in Area 2 (i.e. Antigonou str.), were selected. The streets have the same orientation, i.e., 20° from north, and the monitoring points were located approximately at a height of 5m above street level, centred in the middle of the street width.

Building scale: Three adobe buildings with tripartite arrangement and central portico spaces were selected for environmental monitoring, located on the aforementioned-street canyons, as shown in Fig.. Specifically, the building located on Perikleous street in Area 1, is a characteristic double-storey building with a portico and a timber projecting volume sahnisi on the first floor, covering approximately 210m2 of indoor space.

The double-storey building on P.P. Germanou street in Area 1, and the single-storey building on Antigonou street in Area 2, cover indoor spaces of approximately 120m2. Furthermore, the impact of various window operation patterns was quantified, given the variability of the background wind and the street geometry.Each ventilation scenario comprises variable time of opening, namely: all-day, daytime, night-time ventilation or no ventilation, as well as different percentages of opening (described through the indicator Window-to-Floor percentage – WTF) in cross-ventilation or single ventilation mode.It is noted that applying cross-ventilation in the ground-floor porticos was not always an option as either, a) the opening above the main entrance door (locally called arsera or phengitis) was not operable, or b) the glazed surfaces incorporated on the main entrance door remained closed due to safety reasons. Finally, indoor thermal comfort was assessed through the adaptive comfort theory30. Additional parameters of relative humidity and air velocity were also taken into consideration.

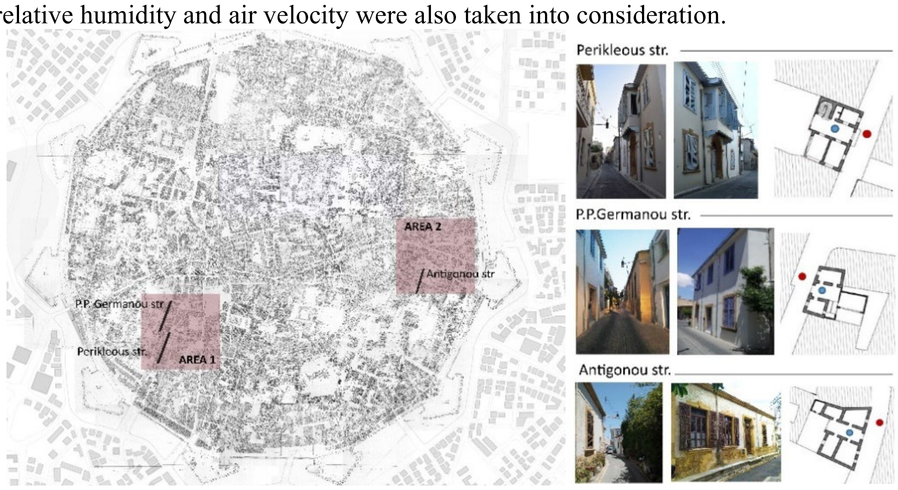

Fig. 4. Case study urban buildings and urban canyons.

3 Results and discussion

3.1 District level of study

The holistic analysis of the district level of study revealed that the early drafting of the street network was on the north-south axis, favouring south orientation for the buildings. The city's fortification, unprecedented housing demand and multiple phases of land allotment, finally defined an urban canopy with both environmental virtues and limitations, e.g., narrow streets that provide shading during the summer, yet suffer from reduced potential for long-wave radiation during summer nights. Respectively, the building typology analysis highlighted the climatic adaptability of vernacular forms that is achieved through a series of elements, e.g., the courtyards, semi-open spaces adjacent to the main building volume, the cross arrangement of the windows and the sahnisi volumes that provide multiple window operation possibilities to the occupants. Based on the city's topographic map, approximately 40% of vernacular buildings in the walled city of Nicosia incorporate portico spaces in semi-open or closed form, that are widespread across the city (see Fig.). The majority of the porticos, specifically 78% of the identified cases, correspond to the central part of a three-bay arrangement, 22% correspond to double-bay buildings, while single-bay porticos are very rare.

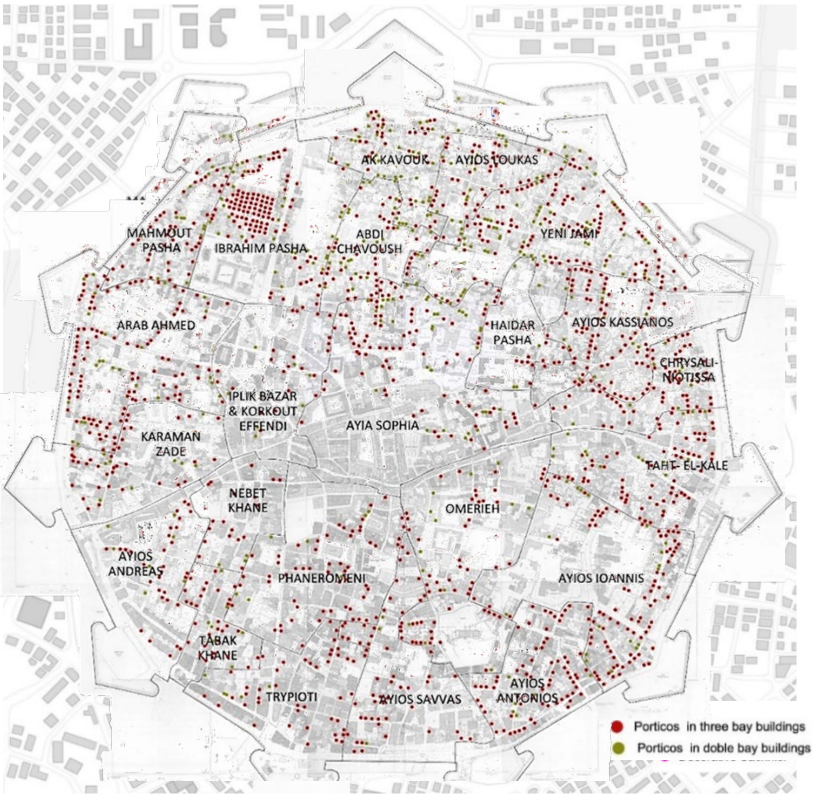

Fig. 5. Spatial distribution of porticos across the walled city of Nicosia.

The mapping process also identified 233 buildings with closed sahnisis and a total of 246 sahnisi projections. Most of the timber sahnisis are located in narrow canyons with aspect ratio 1≤H/W≤2. The insolation analysis confirms the existing knowledge that direct light penetration in porticos located in narrow canyons is limited, while the first-floor portico and the sahnisi spaces are sunlit throughout the year[31]. It is deducted, that wide canyons with aspect ratio 1 could better accommodate the needs of deeper porticos. Respectively, a greater size of projection for the sahnisis would be preferable in wider canyons, for shading reasons. However, no significant correlation between the typical dimensions of the porticos or the sahnisis, with the street canyon geometry was found. Also, approximately 75% of the porticos are elongated spaces with 1≤L/W≤3, which results in limited direct solar gains in ground-floor porticos. This demonstrates that the decisive parameters for the definition of the porticos' and sahnisis' morphology, were more associated with functional and structural aspects, rather than climatic ones. This finding is also pronounced when we look into the orientation of the main facade of the sahnisis. As observed, there is no correlation between the number of sahnisis' windows and the orientation, while window to wall percentage on the main facade did not differ significantly according to the canyons' aspect ratio. Detailed results regarding the interdependence of the urban and morphological aspects of buildings in the case study area are published in[32].

Finally, according to the mapping process, in approximately half of the cases of buildings with timber sahnisis, the porticos' axis is aligned with the prime wind direction in the summer i.e., orientated E-W or NW-SE, which leads to the enhancement of wind-induced ventilation. In the remaining sample of buildings with sahnisi and portico, the proper operation of the sahnisis' lateral openings for capturing the low-speed wind of street canyons is crucial. This highlights the role of occupant behaviour, and the importance of interacting with the envelope, in order to respond to urban constraints in the best possible way.

3.2 Neighbourhood and street canyon level of study

The outdoor field measurements demonstrate the daily variation of wind, which is in line with other field studies conducted in the area[33,34]. Peak wind speed in the afternoon (around 17:00) is substantially weaker during the night, while the main wind direction is W and WSW, i.e., perpendicular to the street canyons under study and aligned to the porticos' axis of the selected case study buildings. Moreover, wind speed in the street canyons is approximately one third of the reference wind speed, which is in line with other studies[35]. However, the dispersion of the field measurements that was recorded in this study highlights that flow in heterogeneous street canyons is much more complex than in simplified idealised street canyon models, as affected by the local asymmetry.

Regarding air temperature, it is observed that street canyons present systematically higher temperature levels than those occurring at the reference point, which depends on the canyon geometry. More specifically, mid-day temperatures in the square-cavity canyon reached up to 1.5°C higher than the reference temperature, while the corresponding temperature difference in the two narrow canyons reached up to 0.6°C[36]. Relative humidity levels in all the outdoor monitoring points did not differ significantly. In all, the observed thermal differentiations highlight the importance of considering the environmental conditions of the street canyons – rather than those recorded at a reference height – as more representative of the buildings' boundary conditions.

3.3 Building level of study

According to the airflow field measurements, long calm periods were monitored in the examined porticos. This indicates a limited potential for comfort ventilation due to insufficient air velocity to produce a cooling sensation. In fact, the percentage of air velocity measurements above the accuracy threshold of the equipment (which is 0.1m/s) in the ground-floor porticos were less than 11% (maximum air speed reached 0.2m/s), which is approximately one fifth of the canyon's wind speed. During the daytime ventilation experiment, the highest indoor air velocity was recorded in the first-floor portico of the building with sahnisi and reached up to 0.6m/s, which demonstrates the wind-capture potential of the sahnisi.

The potential for wind-driven ventilation rises during late afternoon (after 17:00), when winds are consistently stronger and outdoor temperatures cooler. Cross-ventilation in this case, is enabled through windows on the E-W facades, i.e., porticos' axis aligned to the prevailing wind direction. The location of the courtyard on the west side of the plot further promotes the cooling capacity of natural ventilation, as it drives fresh, cool air towards the indoor spaces. In cases of porticos with a N-S direction, i.e., street canyons along the E-W axis, the cross arrangement of the porticos' windows, along with the existence of the courtyard, play a fundamental role in directing west wind towards the interior spaces and enabling cross-ventilation. In this case, when a second-floor with a sahnisi projecting volume is present, the lateral openings of this element are crucial (perpendicular to the wind direction flowing along the canyon). Respectively, during the night, wind-driven ventilation is not effective as wind speed is minimum; yet, night-time ventilation is particularly beneficial in reducing indoor temperatures through convective heat exchange.

Reflecting on the observed occupant behaviour, when occupants were aware of the way thermal mass works and maintained greater ventilation rates at night, thermal comfort was achieved for the majority of the time. However, in some cases, occupants seemed to ignore an apt window operation pattern, or were unable to apply such due to practical reasons (e.g., their occupancy schedule, safety or difficulty in accessing upper windows). Finally, the results of the ventilation experiments (particular ventilation patterns applied by the researcher) indicated that a moderate percentage of opening is recommended to avoid overcooling and elevated relative humidity levels (especially in more humid regions of the Mediterranean, such as coastal areas). In the case of buildings with portico and sahnisi, the recommended WTF ratio on the ground floor is 9% and on the first floor, 13% (i.e., open windows and applied shutters)[37].

3.4 Open field for future research

Despite the intrinsic passive ventilation strategies incorporated in vernacular buildings, readjusting the research methodology in order to acquire neighbourhood scale morphometric variables is an open research direction. The results of this study offer a valuable background and starting point; however, a greater number of cases would be necessary to draw conclusions on potential correlations. Future studies could adopt this approach and create a database addressing building and urban scale morphometric characteristics, coupled with environmental monitoring data.

Given the social, cultural and financial assets of the free cooling potential of natural ventilation, as well as its environmental benefits quantified in this study, it can be argued that certain urban scale policies should promote the continuation of this practice. This would require action and research in the direction of improving air quality, lowering noise pollution, mitigating the effects of climate change and inspiring safety through means of governance in historic centres. Finally, in order to enhance cross or buoyancy driven ventilation, especially in ground-floor spaces, action should be taken in the direction of raising awareness amongst residents regarding efficient window opening behaviours in heavyweight buildings, as well as providing more practical, accessible and safe ways to operate windows, that explore the potential of smart opening mechanisms with the aid of technology.

4 Conclusions

As acknowledged, vernacular buildings encompass many environmental virtues, yet the roles of urban density, street orientation and geometry, as well as the variability of the background wind, are often neglected in relevant studies. The work presented in this paper addresses climate-responsive practices in urban vernacular heritage, emphasising the strategy of natural ventilation in the Mediterranean climate. The originality and significance of the presented research lies within the adopted methodology that investigates the climatic challenges and opportunities of vernacular dwellings on multiple scales. The district level of study corresponds to the wider historic centre under study, i.e., the walled city of Nicosia, where analytical tools were employed to, a) reinterpret the drafting of the city through an environmental lens, and b) decipher the role of urban morphology in the environmental performance of vernacular dwellings.

Through the employment of analytical tools at a wider scale (district level), it was made evident that besides the environmental factors, functional and morphological parameters have also emerged as decisive in the configuration of these architectural elements and their integration into the urban fabric. This is an important aspect to keep in mind when it comes to environmentally friendly conservation projects, so as to apply critical thinking on enhancing the environmental benefits of these features.

Environmental monitoring of the neighbourhood, street canyon and building levels highlighted the complexity of airflow in real inhomogeneous urban canopies. As demonstrated, air velocity level in the street canyons is approximately one third of the reference free-stream wind velocity, while indoor air velocity remains at minimum levels, reaching up to one fifth of the canyon's wind speed. This indicates the importance of considering the environmental conditions in the urban canyons, as they better describe the boundary conditions for building ventilation. Furthermore, the comparative analysis of the examined ventilation patterns revealed best practices for enhancing the cooling effect of natural ventilation, highlighting the benefits of night-time ventilation, as well as the importance of having energy-aware occupants. Moreover, through this research, the role of the sahnisi as a wind-capture element in dense urban canopies, was quantified under real field conditions. Finally, given the social, cultural and financial assets of natural ventilation, this research argues that urban scale policies should promote the continuation of this practice through means of governance in historic centres.

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Personalized Services for Smart Grids in the framework of Society 5.0: A Smart University Campus Case Study

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Abstract. The evolution of the power grid towards a Smart Grid is a crucial aspect of the transformation of society towards the so-called Society 5.0, where human-centered technology is the key to addressing social challenges. This paper proposes a personalized service approach for Smart Grids within the Society 5.0 framework, which aims to provide personalized energy management services to consumers through advanced sensing technologies, intelligent algorithms, and social and contextual data. Furthermore, the paper highlights the potential of personalized services in the Smart Grid context and their relevance in the Society 5.0 framework and proposes an architecture for the design and deployment of personalized energy management services in other Smart Grid contexts. In this approach, end-users play an active role in the design and deployment of personalized energy management services. The proposed methodology is tested and evaluated in a Smart University Campus case study. The results indicate an improvement in energy management and a reduction in energy consumption.

Keywords: Smart Grid, Society 5.0, Personalization, Smart Campus, Digital Twin

1 Introduction

As the Industry 4.0 manufacturing paradigm has reached the plateau of productivity [1], the industrial and manufacturing landscape is shifting towards the implementation of Society 5.0 [2,3], a concept developed by the Japanese government [4,5]. This concept requires a comprehensive digital transformation across various sectors, including energy [6]. Smart grids, an intelligent electricity distribution network, play a critical role in optimizing energy generation, transmission, and consumption [7]. With the increase in renewable energy sources, the integration of electric vehicles, and the emergence of new technologies, smart grids have become more complex, requiring innovative solutions to manage them efficiently [8].

According to [9], during 2021, the smart grid market reached a value of $43.1 billion on a global scale. According to projections, the smart grid industry is expected to reach $103.4 billion by 2026, reflecting a Compound Annual Growth Rate (CAGR) of 19.1% during the period of 2021 to 2026. The World Economic Forum (WEF) report [10] highlights the increasing demand for renewable energy sources, government initiatives for smart grid implementation, and technological advancements in the energy sector as key factors driving market growth.

Personalized services [11] in smart grids are essential to optimize energy consumption at the individual level, improving energy efficiency and reducing costs [12]. According to a study by McKinsey& Company, personalized services in the energy sector can reduce household energy consumption by up to 15% [13]. Therefore, the implementation of personalized services in smart grids is crucial to achieve the objectives of Society 5.0 and to address the growing demand for energy efficiency, cost-effectiveness, and sustainability [14]. The contribution of this manuscript is focused on the design and development of a smart grid framework, which is applied to a university campus [15, 16]. The aim is to achieve electrical energy democratization [17] in the public infrastructure domain, and to design and develop the Digital Twin (DT) of Product Service System (PSS) Smart Grid (SG) Platform.

The remainder of the manuscript is structured as follows. In Section 2, the most pertinent literature is investigated towards the next generation of industry, i.e. Industry 5.0. Then, in Section 3, the architecture of a smart grid for a university campus is presented and discussed. In Section 4, the implementation of the proposed study is presented. In Section 5, results are presented. Finally, the manuscript is concluded in Section 6 along with the provision of future research steps.

2 Literature Review

2.1 From Energy 1.0 to Energy 4.0 and beyond

The concept of Energy 4.0, which falls under the umbrella of Industry 4.0, refers to the digital transformation of the energy industry. It is important to define Energy 4.0 in detail as it is closely linked to its evolution, Energy 5.0. This concept covers various aspects of the energy sector, including energy generation, distribution, storage, and marketing. The reason for this is that the physical world is changing rapidly with issues such as intermittent renewables, nuclear power, and new transmission and distribution grids, among others. Additionally, changes in the commercial energy landscape, such as unbundling, trading, and new product offerings, are also driving the need for Energy 4.0. The growth in the collection and flow of large datasets is also a critical factor in this transformation [18].

In Figure 1 the correlation between energy and the different industrial revolutions throughout history is illustrated. The first industrial revolution is chronologically placed in the late 18th century, introducing mechanized production as a replacement for manual labor. Approximately a century later, the second industrial revolution was sparked by the widespread adoption of electricity in industrial processes and the establishment of global electrical grids. During the third industrial revolution the integration of automation and computers to further enhance production optimization was prioritized. Presently, the fourth industrial revolution, also known as Industry 4.0, capitalizes on smart and interconnected systems to boost flexibility and productivity. This interconnectedness among machines, systems, and devices within and between industrial sites has resulted in heightened intelligence. By leveraging the shared characteristics of sustainable energy transition and Industry 4.0, the path towards Industry 5.0 can be paved, achieving a sustainable energy transition [19].

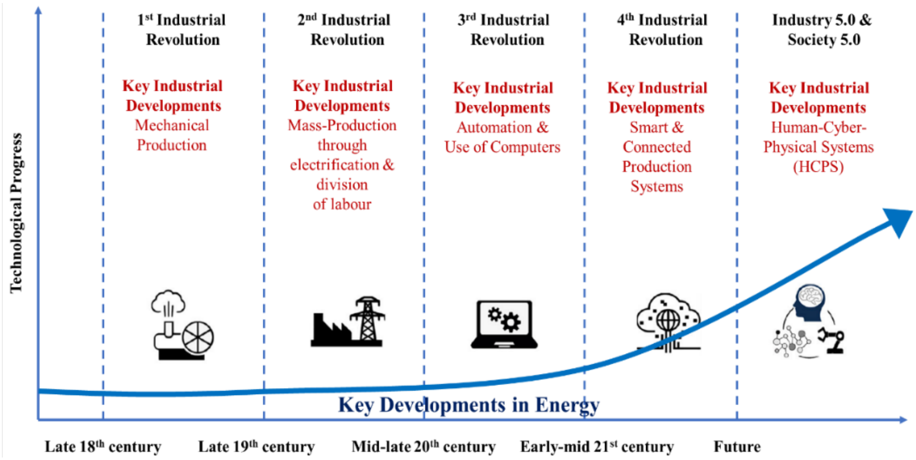


Fig. 1. Energy development milestones in correspondence to the Industrial Revolutions [20].

2.2 Smart Grids (SGs)

Up to now, energy production has primarily relied on burning fossil fuels and following a centralized system of transmitting and distributing energy in one direction [21]. During the transmission phase, electrical energy is transferred from power plants to consumers through substations with the utilization of electric cables. However, this process lacks sufficient i) real-time feedback, and ii) monitoring mechanisms. Due to the limited data flow and the sharp rise in energy demand, blackouts may occur frequently, posing a significant risk to human life [22]. Therefore, the current grid requires modernization [23]. The Smart Grid (SG) is an electrical distribution system that employs state-of-the-art digital technology to facilitate bidirectional communication between stakeholders. By constantly monitoring, analyzing, and controlling the flow of electricity, valuable information can be gleaned to create a more intelligent, adaptable, and dependable grid capable of forecasting energy demand and costs. As cited in [24], it is projected that by 2023, around 65% of electricity companies will have allocated investments towards advanced digital technologies, facilitating the introduction of innovative smart services. The SG incorporates several important features to achieve its goals. These include [25]:

1. Energy demand response support, which aims to reduce costs by providing advice on device usage during peak demand periods when prices are higher.
2. Efficient load handling to decrease the duration of peak hours and improve stability.
3. Decentralized energy production, which enables individuals or third-party stakeholders to contribute to the power grid using renewable energy sources.

By integrating smart meters, producers, and consumers, the Smart grid offers new characteristics and possibilities that aim to provide sustainable, economical, and efficient energy supply [26]. The model encourages consumers to become "prosumers" by contributing to the grid through energy production, sharing, or selling. As a result, consumers become an essential part of the grid's functionality and can optimize their energy decisions based on their energy demand. Prosumers generate energy from renewable sources, such as PV arrays or wind turbines, and share it with other consumers on the grid. The grid follows bidirectional data and energy flow between stakeholders, which can provide valuable information for optimizing the grid's function and energy distribution [27,28].

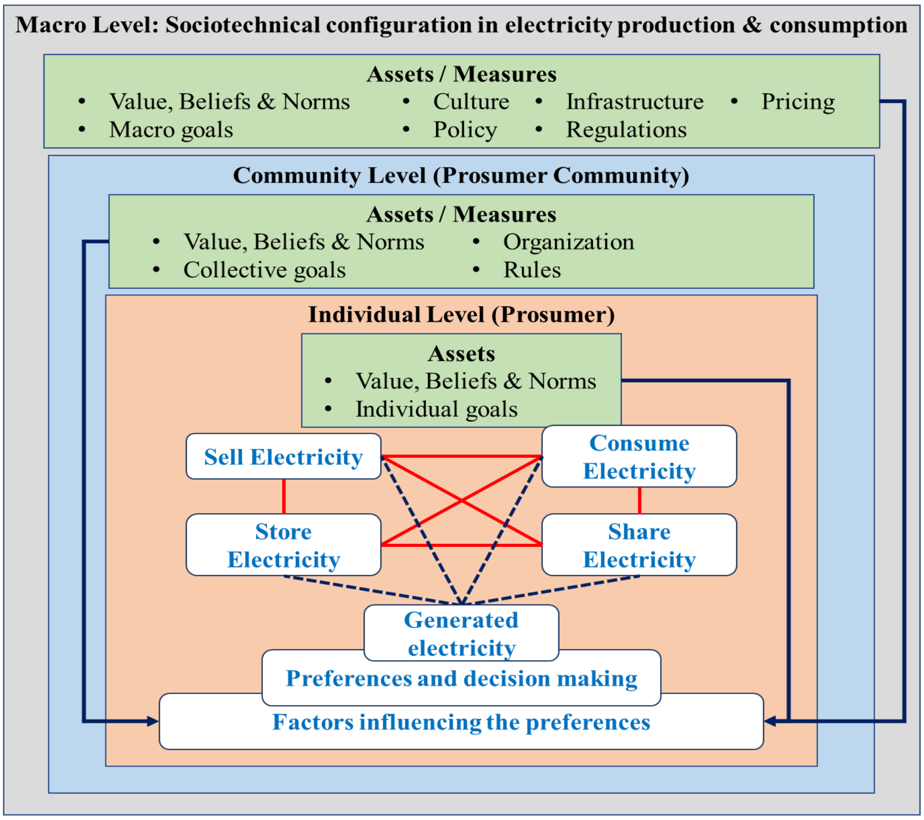


Fig. 2. Prosumers uses of energy [29].

Figure 2 demonstrates the key features of the prosumer profile. Prosumers are distinct from regular consumers because they are viewed as an upgraded version of them and offer substantial benefits for managing their energy and the overall power grid. As a result, Table 1 highlights the primary distinctions between these two energy client profiles, clarifying why prosumers can establish the foundation for the implementation of intelligent grids.

Table 1. Comparison of Consumer energy profile versus Prosumer.

Consumer	Prosumer
Consumes energy	Consumes, produces, shares, stores, sells energy
Has access to static data	Has access to dynamic data, better informed
Deploys non-renewable energy sources	Deploys renewable energy sources
Physical presence for device use	Remote use of device, flexible
Vulnerable to blackouts	Safer against blackouts
Not many possibilities for electricity cost management	Can manage electricity cost with better insight
Does not protect the environment	Protects the environment

2.3 Smart Grid Technologies

Smart grid technologies refer to advanced systems that integrate information and communication technologies (ICT) with power grids, enabling real-time monitoring, control, and automation of energy delivery. These technologies facilitate bidirectional communication between electricity suppliers and consumers, allowing for dynamic energy management and consumption optimization. Smart grid technologies incorporate various components, such as smart meters, sensors, advanced communication networks, and data analytics tools. They help utilities to better manage power distribution, reduce energy wastage, and improve grid reliability and resiliency. Furthermore, smart grids can accommodate distributed renewable energy sources and electric vehicles, paving the way for a more sustainable and efficient energy future [30].

2.4 Cybersecurity and Blockchain in Smart Grids

With the increasing digitization of the energy sector, ensuring the cybersecurity of smart grids has become critical. Smart grids are highly interconnected, and any breach in their security could have severe consequences, including blackouts and power disruptions. Blockchain technology offers a promising solution to enhance the cybersecurity of smart grids. Blockchain, with its decentralized architecture, provides a secure and transparent system for data storage and sharing. By implementing blockchain in smart grids, utilities can ensure the integrity of the data, prevent cyber-attacks, and protect consumer privacy. Blockchain can also facilitate secure peer-to-peer energy transactions, enabling consumers to trade energy directly with one another [31]. However, the implementation of blockchain in smart grids faces several challenges, including interoperability, scalability, and regulatory issues. Addressing these challenges is crucial for the successful integration of blockchain into smart grids and enhancing their cybersecurity [32].

The Society 5.0 framework envisages the Smart Campus as a digitally advanced and interconnected system that uses cutting-edge technology to elevate the quality of education, research, and campus life [33]. As the Smart Campus operates through interconnected devices and data exchange, it is crucial to ensure the security and privacy of personal information and campus assets through cybersecurity and blockchain [34]. By implementing measures such as access controls, identity management, and threat detection systems, cybersecurity can prevent malicious attacks and data breaches in the Smart Campus. Furthermore, blockchain can establish a transparent and secure platform for managing and sharing data across different departments and stakeholders in the Smart Campus [35]. This will enhance data integrity and accountability while enabling peer-to-peer transactions, smart contracts, and other decentralized applications that can improve the efficiency and effectiveness of Smart Campus operations [36]. Summarizing, incorporating cybersecurity and blockchain into the Smart Campus is crucial for realizing the Society 5.0 framework's full potential, creating a secure, sustainable, and prosperous future for all.

3 Methodology and System Architecture

The growing energy demand and need for new solutions have led universities like Birmingham City University [37] and University of Glasgow [38] to invest millions of dollars to transform into smart, self-sustainable campuses. By reducing energy costs and CO2 emissions, these universities can serve as micro cities to test new ideas and promote a healthy, clean, and economic environment to students. Implementing sustainable practices in universities not only protects the environment and minimizes energy costs, but also promotes impact consciousness and education of future generations. However, creating a smart university requires consideration of multiple parameters, and a detailed recording of data is necessary to cover every level of the system. The proposed system includes smart buildings equipped with IoT devices, sensors, and actuators that interact with the digital world, enabling intelligent prediction and decision making. The system aims to optimize energy distribution by detecting and studying several parameters that affect building efficiency, such as air conditioning units, boilers, LED lights, and gas sensors. A large volume of data is created, which needs to be transferred and aggregated to the management center through communication protocols and cloud servers for processing and analysis using the digital twin.

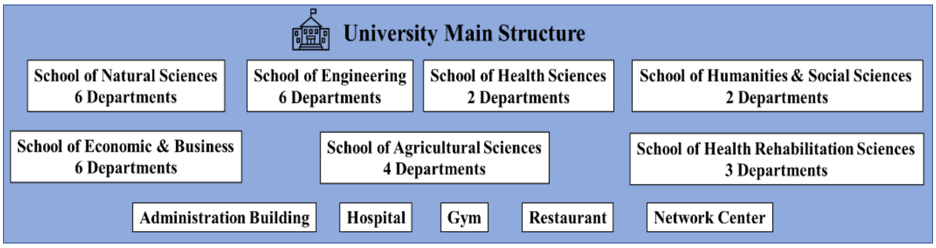


Fig. 3. University Campus Main Structure.

Table 2. University Campus Buildings for Monitoring

Building	Description
A	Administration Building
B	Hospital
C	Conference Center
D	Network center
E	Restaurant
F	Student Residence Hall
G	School of Engineering – Department 1
H	School of Engineering – Department 2
I	School of Engineering – Department 3
J	School of Engineering – Department 4
K	Gym

3.1 Cloud Platform

This paper focuses on designing and developing a Smart Grid system based on a Digital Twin implementation to optimize energy profiles for customers. A fundamental and primary element of the Smart Grid system involves establishing a customizable Digital Twin (DT) framework, which is used i) for the representation of critical elements, and ii) for facilitating the integration of new customers into the electrical energy distribution network. The implementation of the framework is based on the development of a Cloud platform that offers a range of services, including customer registration, energy consumption monitoring, and power plant creation/editing capabilities among others. Users are divided into three categories: Energy Providers, Customers, and System Administrators, each with specific roles and responsibilities. The Energy Providers user group is responsible for managing critical parameters within the Smart Grid to prevent overloading and to facilitate the temporary disabling of specific areas for maintenance purposes. The Customer's group is further classified into sub-categories such as Industrial, Professional, Office, Domestic, Organization, and Roads to prioritize energy consumption. For instance, hospitals are prioritized to ensure uninterrupted power supply. In conclusion, the System Administrator user group plays a vital role in the establishment of a smooth connection between the Cloud platform and the Smart Grid. Further to that, they also ensure that the Digital Twin model is constantly up to date when changes occur, such as when new users are added, or existing ones are removed. The platform offers customers a monitoring panel for the visualization of their real-time energy profile. In the current study the significance of implementing Digital Twin technology in Smart Grid systems is investigated, as it empowers energy consumers to further optimize their energy consumption in alignment with the overall demand of the electricity network. Consequently, this implementation leads to a more sustainable and efficient energy distribution system.

3.2 Data Acquisition and Monitoring Device

To ensure the effective implementation of the proposed system architecture and the seamless integration of the physical system(s) with the Digital Twin, it is essential to incorporate monitoring equipment for capturing relevant parameters. This entails the installation of a set of Data Acquisition devices. The modules within each device are categorized as discussed earlier. The Smart Grid nodes commonly employ sensing equipment for measuring the following: i) Light intensity, ii) micro-climate temperature, iii) micro-climate humidity, iv) current draw, and v) motion within the buildings. Some key characteristics of the sensors utilized through the nodes of the smart grid are summarized as follows [39]:

- **Light sensors** used in a smart grid must be accurate, reliable, and able to detect a range of light levels. They should have a fast response time, low power consumption, and be able to communicate wirelessly. Additionally, they should be resistant to environmental factors such as temperature, humidity, and dust.
- **Temperature sensors** used in a smart grid should be accurate and reliable, with a fast response time and low power consumption. They must be able to measure a wide range of temperatures and be resistant to environmental factors such as humidity and dust. Additionally, they should be able to communicate wirelessly and have a long battery life.
- **Humidity sensors** for a smart grid need to measure the amount of water vapor in the air accurately. They should have a wide measurement range, high accuracy, low power consumption, and be able to communicate wirelessly. They must also be robust and reliable, able to withstand harsh environments and have a long lifespan.
- **Current draw sensors** for a smart grid must be capable of measuring both AC and DC currents, with high accuracy and resolution. They must also be able to operate over a wide temperature range and have low power consumption. The sensors must be reliable and able to provide real-time data to the control systems for load balancing and demand response purposes.
- **Current motion sensors** for a smart grid must be able to detect movement in electrical current flow and provide accurate and timely data for monitoring and

control purposes. They should have high sensitivity, fast response time, low power consumption, and the ability to operate in harsh environments. The sensors must also be compatible with communication protocols used in the smart grid and have sufficient data storage capacity for logging current readings over extended periods.

3.3 Digital Twin

The primary objective of the Digital Twin (DT) module is to facilitate the near real-time monitoring of the buildings (refer to Figure 3 and Table 2) within the Smart Grid, allowing for the simulation of power generation and distribution. Additionally, the DT plays a crucial role in minimizing unnecessary power consumption by aiding in the modeling process and utilizing data collected from the individual sensing devices mentioned earlier.

One important parameter calculated by the DT is the Indoor Environmental Quality (IEQ) [41]. The IEQ is a comprehensive metric that encompasses Visual Comfort (VC), Thermal Comfort (TC), and Indoor Air Quality (IAQ). In this approach, the IEQ is measured on a scale from 0 to 100, with 100 representing “optimal quality”. Calculating the IEQ requires the fusion of information from various sensors [42].

Another aspect of the DT pertains to the road network connecting the buildings within the campus. By implementing an intelligent algorithm that takes into account factors such as time of day, environmental lighting, and traffic measurements, the lighting system can be automatically adjusted to provide the minimum required illumination [43].

However, to establish a reliable and continuous communication with the physical system, it is crucial to employ an appropriate communication framework, which is discussed in the next Section.

3.4 Communication framework

The communication framework serves as a vital component within the Smart Grid infrastructure. Its seamless and uninterrupted operation is crucial to ensure the continuous functionality of the Smart Grid system. To facilitate data acquisition, a Wireless Sensor Network (WSN) is implemented. The WSN follows a star topology, allowing for a single local network coordinator (Master) and multiple sensing nodes (Slave) to coexist. Each sensing node is equipped with sensors, a central data-gathering board, and an RF/Bluetooth antenna for wireless connectivity to the network coordinator. Figure 4 provides a visual representation of the star topology. The network coordinator is responsible for collecting data from the connected sensing nodes and organizing it into a structured file format, such as XML. The data files are transmitted back to the Cloud Database, where the identity of the network coordinator and WSN is included with each XML file to ensure proper classification of the data from each node.

Therefore, based on the above mentioned, in order to develop a digital twin for a smart grid requires the installation of smart sensors both inside and outside a university building to collect data about the building's energy usage and performance. Therefore, the following steps were followed in order to install the appropriate sensors (i.e., Motion sensor, Temperature and Humidity sensor, and Photoresistor - Fig. 5):

1. **Selection of Points for Installation:** Before installing any sensors, conduct a thorough site survey to identify the areas where the sensors will be installed. This will help you determine the optimal locations for sensors, the number of sensors required, and the type of sensors needed.
2. **Sensors Selection:** There are many types of sensors available for monitoring energy usage and building performance, such as temperature sensors, occupancy sensors, light sensors, and energy meters. Choose the appropriate sensors based on the data you need to collect and the areas you want to monitor.
3. **Sensor Installation:** Once you have identified the optimal locations for the sensors, install them. This may require running wires and cables, drilling holes, and mounting the sensors in the appropriate locations. Make sure to follow the manufacturer's instructions for installation and wiring.
4. **Connect the sensors to the network:** Once the sensors are installed, they need to be connected to the network so that they can send data to the digital twin. This can be done using Wi-Fi or Ethernet cables, depending on the type of sensors and the network infrastructure.
5. **Sensor Configuration:** Each sensor will need to be configured to send data to the digital twin. This may require setting up IP addresses, configuring data transmission rates, and setting up authentication and encryption protocols to ensure data security.
6. **Digital Twin Configuration:** Once the sensors are installed and configured, set up the digital twin to receive data from the sensors. This may require setting up a cloud-based platform or an on-premises server to collect, store, and analyze the data.
7. **Data Monitoring**: Once the sensors are sending data to the digital twin, monitor and analyze the data to identify patterns and trends in energy usage and building performance. Use this information to optimize energy usage and improve the building's performance.

The Information and Communication Technologies used for the implementation of the proposed system are explained in a detailed manner in Section 4 and Section 5.

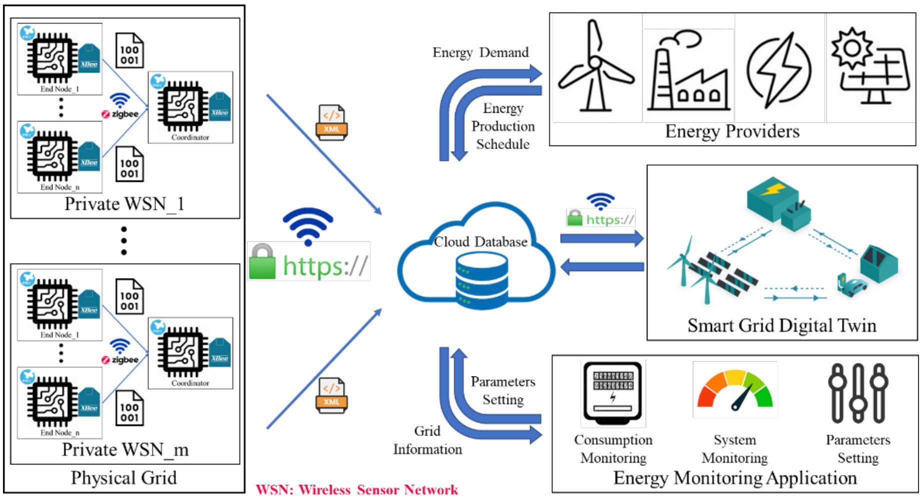


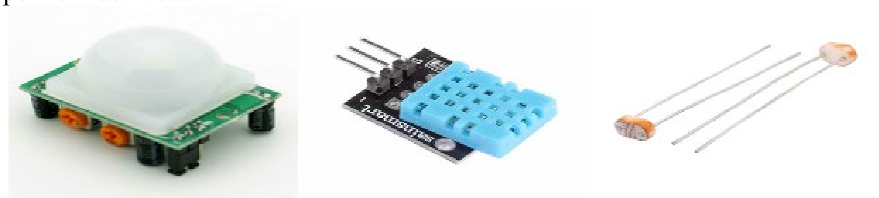
Fig. 4. Architecture of the proposed system (Developed by Authors).

4 System Implementation

The implementation of the proposed method is based on the integration of a multi-sensing device for acquiring environmental data from each of the buildings involved in the smart grid. These parameters involve the indoor environment conditions as well as the logging of the electrical energy consumption, so that they can be processed from the corresponding DT and consequently to provide suggestions of the optimization of electrical energy utilization. In simple terms, a sensor is an input device that detects physical events by modifying its electrical properties and converting them into measurable analog or digital signals with the assistance of a Micro Controller Unit (MCU). This allows human operators to observe, read, save, and further process the data in order to optimize the system. Sensors can be classified into various categories based on their working principles, including the need for an external signal, detection method, conversion method, and output signal type.

The first category distinguishes sensors as active or passive, depending on whether they require an external signal to function. Active sensors rely on a signal, while passive sensors generate an output response without external excitation. Sensors can also be classified as electric, chemical, or radioactive based on the detection method. The third classification is based on the conversion phenomena, such as thermoelectric or photoelectric conversions. Lastly, sensors can be categorized as analog or digital, where analog sensors produce continuous analog signals and digital sensors produce binary signals.

For instance, a Light Dependent Resistor (LDR) photoresistor, which is affordable and has a simple structure, is used for luminosity measurement. It is made of semiconductor materials that exhibit changes in electrical conductivity when exposed to light (photons), disrupting the material's electrical stability. This disruption creates an electric signal that can be captured by the system, although sometimes an amplifier is required to transmit the data to a computer. The resistance capacity of this sensor decreases whenever a light beam falls on the LDR cell and increases whenever no light source is present. The minimum response time is approximately 55 milliseconds for sensing any light change and approximately 45milliseconds are required in order to transmit the measured signal to the microcontroller. Furthermore, some extra characteristics are the high sensitivity, fast respond time and low-cost, making sensors reliable and more accessible to companies and users to build advanced automated systems based on them. In Figure 5, the sensors used for the implementation of the functional prototype are illustrated.



a) b) c)

Fig. 5. (a) Motion sensor, (b) Temperature and Humidity sensor, and (c) Photoresistor.

In the current research temperature, humidity and luminosity are taken into consideration as parameters (see Table 3), for the representation of the indoor environment conditions in order to facilitate the representation of the physical environment to the digital twin.

Table 3. Environmental monitoring parameters and their measurement methods.

Variable	Parameters	Measurement
T1	Air temperature (°C)	Temperature sensor
H1	Humidity (%)	Humidity sensor
L1	Luminosity (Lux)	Photoresistor

Specifically, in Table 3 information on the variables, units, and detection sensors associated with each parameter are provided. The variables for internal parameters are represented by two symbols, a letter followed by the number 1, while external parameters are denoted by a letter and the number 2. The units used in the table are degrees Celsius (°C) for temperature, percentage (%) for humidity, and lux for luminosity, which is equivalent to one lumen per square meter.

For temperature and humidity detection, the DHT11 sensor is utilized, which is capable of measuring both variables. This sensor incorporates a resistive-type humidity measurement component and a negative temperature coefficient (NTC) thermistor. The NTC thermistor exhibits a decrease in resistance as the temperature increases, leading to an increase in conduction electrons due to the thermal effect. Additionally, an 8-bit microcontroller is employed to output the values as serial data, making the system function as a temperature and humidity module. Table 4 presents the characteristics of the

DHT11 module, while Table 5 provides the technical specifications of the light-dependent resistor (LDR) used for luminosity measurements.

Table 4. DHT11 characteristics.

Technical Specification	Value Range
Temperature measurement range	0ºC to 50ºC
Humidity measurement range	20% to 90%
Temperature accuracy	±2ºC
Humidity accuracy	±5%
Operating voltage	3V to 5.5V
Operating current	0.3mA (measuring) 60uA (standby)
Output	Serial data
Resolution	8-bit
Response Time	6sec to 30sec

Table 5. LDR Photoresistor characteristics.

Technical Specification	Value Range
Operating temperature range	-25°C to 75°C
Voltage peak	100V
Current	5mA
Power dissipation at 25°C	50mW
Cell resistance	20kOhm to 100kOhm
Dark resistance	20MOhm
Rise time	45ms
Fall time	55ms
Spectral response	550nm

Having precise knowledge of the internal conditions within each building and comparing them with the real-time external weather conditions is crucial for gaining valuable insights into the system's efficiency. By integrating this data into the Digital Twin (DT), advanced analytic methods and algorithms can be employed to optimize the University's operations. This includes evaluating and controlling the Heating, Ventilation, and Air Conditioning (HVAC) system to ensure it is performing optimally. Additionally, assessing the electricity cost is essential to evaluate the entire system, while considering all the gathered data.

To establish a remote monitoring system, the data needs to be transferred to servers or the cloud via the Internet for storage and aggregation. Wi-Fi modules, which are cost-effective system-on-a-chip devices, provide a complete Wi-Fi networking solution in a single chip. These modules come with integrated antennas and other components, such as CPUs, facilitating easy and fast connection and operation. Moreover, Wi-Fi network modules support software tools and communication protocols, enabling connectivity with Arduino for remote data exchange and system management.

To enable the Wi-Fi connection between the local network and the data acquisition device, the ESP8266 ESP-01 Wi-Fi module is utilized in this research. This module is designed for mobile platforms with restricted space and power, offering extensive Wi-

Fi capabilities while being cost-effective and occupying minimal space. It integrates various components, including an antenna, power amplifier, low-noise receive amplifier, filters, power management modules, and internal SRAM. It can be easily integrated with sensors and other devices through its GPIO pins, allowing for versatility according to user requirements. During programming, specific characteristics and access codes related to the Wi-Fi module and network, such as module type, baud rate, Wi-Fi key, and ID, need to be defined to establish a stable and reliable data flow.

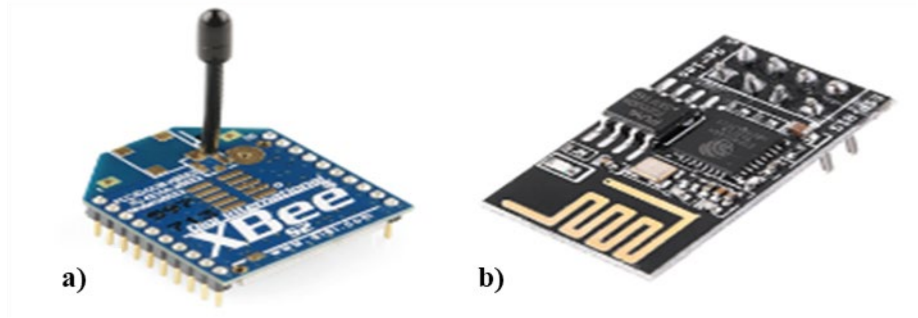


Fig. 6. (a) XBee RF module, (b) ESP8266 WiFi module.

5 Case Study

5.1 Data Acquisition Device

The system architecture implementation revolves around the development of the Data Acquisition (DAQ) device, which is considered a fundamental technology and forms the basis of the entire system. The developed DAQ device is responsible for detecting the physical environmental conditions and transmitting the data to designated servers via Wi-Fi. This enables the creation of real-time data charts, representing the precise environment, which can be further analyzed and used for predicting energy consumption throughout the day.

The DAQ device comprises both hardware and software components that work together synergistically. These components will be presented and explained in detail below. The combination of these components offers limitless possibilities, catering to a wide range of applications, as numerous detection methods and sensors are available to meet the specific needs and goals of the user.

Our customized data acquisition device is specifically programmed to measure temperature, humidity, and luminosity within the selected buildings of the university. This is achieved by connecting the appropriate equipment to the chosen microcontroller. Detailed information regarding the components and circuitry of the device can be found in Table 6, and a visual representation of the prototype is provided in Figure 7.

Table 6. Data Acquisition device parts.

Parts	Description
Arduino UNO R3	Microcontroller
DHT 11 (3 pins)	Humidity (%) and temperature(°C) sensor
Photoresistor	Luminosity sensor (LDR)
ESP 8266 ESP-01 module	Wi-Fi microchip
Resistances	1kOhm, 10kOhm
Male/ Female Wires	Connect and complete the circuit
Power Supply regulator	Converts power supply from 5V to 3.3V

The microcontroller utilized in this device is the Arduino Uno R3, which is reliable for the entire data acquisition system. The device detects environmental conditions through DHT11 and LDR photoresistor, connected to a breadboard with wires and resistors. The resistors are selected based on Ohm’s law and are necessary for the circuit to function properly. DHT11 already has an integrated resistor, so an additional one is not required. For data transfer, ESP8266 module is utilized, which is a Wi-Fi microchip that establishes a connection with the WLAN and subsequently WAN through the necessary TCP/IP communication protocol suite stack. Additionally, a power supply regulator is incorporated as the ESP8266 module requires a 3.3V input to operate effectively. This regulator supplies the necessary voltage along with a greater amount of current than Arduino’s 3.3V supply pin, which can cause functionality problems. The device functions by taking input from the sensors and outputting data to servers. The microcontroller, programmed using the Arduino IDE, transforms the sensor data into valuable information. Figure 7 illustrates the connection of external sensors. Furthermore, traditional circuitry components like resistors and capacitors have been added to ensure accurate sensor measurements and correct operation of the DAQ device. A 10kOhm resistor is connected to the photoresistor, and the ESP8266 module has a 1kOhm resistor. Each external sensor requires three pin connections to the MCU. The sensors are powered using a 3.3V to 5V DC voltage (red for positive and black for negative/ground pins). An extra wire (blue) is linked to an Arduino analog or digital input/output pin. Three digital pins (6 to 8) and a single analog pin are used in the current setup. The DHT11 sensor is connected to digital pin number 8, the ESP8266 module to pins 6 and 7, and the LDR photoresistor to analog pin A0. The power supply regulator is set to 3.3 volts on one side of the breadboard to guarantee the secure operation of the ESP module and 5 volts on the other side for better sensor efficiency and stability. This provides two different power supply voltages simultaneously, making the device more versatile. Furthermore, using an external power supply makes it easier to use the Wi-Fi module. The on-board 3.3V pin provides low amperage compared to the prototype’s requirements, which can cause system instability and prevent communication with the cloud server.

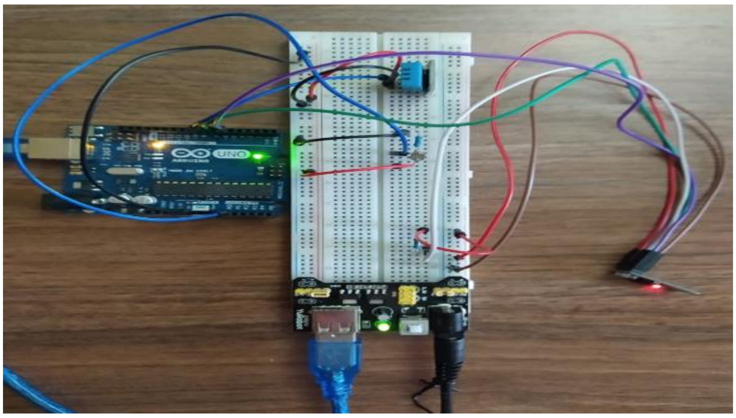


Fig. 7. Data Acquisition device prototype.

The connectivity of the sensors is straightforward but connecting the ESP module to the breadboard and Arduino is a bit more complicated due to the many pins involved. In addition to the ground and power supply connections, the Arduino's RX and TX pins must be correctly connected to the corresponding pins on the ESP module to enable bidirectional communication and constant data exchange between the two. However, not all of the ESP module's pins are necessary, and some, such as the reset pin, can be left unconnected. The system can also be reset using the reset button on the Arduino.

For this study, various sample rates for the data acquisition device were tested, ranging from 30 seconds to 5 minutes. It was found that the building conditions did not change rapidly, so a 5-minute sample rate was selected for more accurate detection of environmental changes. The code script developed for the device stores temperature and humidity as "float" data types and luminosity as "int" data type, each taking up 4 bytes per sample sent to the cloud server platform. This results in 12 bytes being sent every 5 minutes and 144 bytes every hour, well within the limit of ThingSpeak, which can receive messages up to 3000 bytes. The device has been tested with over 10,000 samples with minimal package loss due to network connection interruptions, and live and historical data can be exported for visualization and analysis.

5.2 Results and Discussion

The Graphical User Interfaces (GUI) for live monitoring of the buildings as well as an additional functionality for the setup of high consumptions periods are presented in Fig. 8.

Fig. 8. Graphical User Interfaces for Consumption monitoring and high/low consumption period setup.

Live visualizations of physical conditions within a building can be used in various ways to optimize energy functions. Correlated data plots, such as those presented in Figure 9, can help in better understanding and comparison between variables. For instance, humidity and temperature data can be presented in a single plot to easily observe their relationship, which in this case is inversely proportional.

Comparing live outdoor and indoor conditions can provide valuable insights into the performance of the HVAC system and insulation status, which can inform maintenance and repair activities. For instance, the temperature difference between the inside and outside environments should be around 10°C when the HVAC system is operating. If this threshold is surpassed, a warning message with an adjustment suggestion can be sent to prevent the air-conditioning system from overperforming and reducing its efficiency, thus increasing the overall electricity cost. Regularly detecting high humidity and temperature problems could lead to a more efficient maintenance plan, such as upgrading the equipment or insulation.

Access to the consumed kilowatts of each building is crucial for evaluating the system's economic aspect, which can be obtained from the relevant department. This enables stakeholders to evaluate any future operation, equipment, or shift while considering its economic impact.

The system has the potential for additional enhancements through the integration of smart equipment or actuators, which facilitate near real-time interaction to minimize energy consumption and promote environmental preservation. An illustrative example is the utilization of motion or LDR sensors to automatically control LED lights, resulting in reduced energy usage and cost. To demonstrate this functionality, a small LED light was connected to the prototype of the data acquisition device and programmed to activate automatically when the lux value dropped below 100, indicating a dark and overcast day.

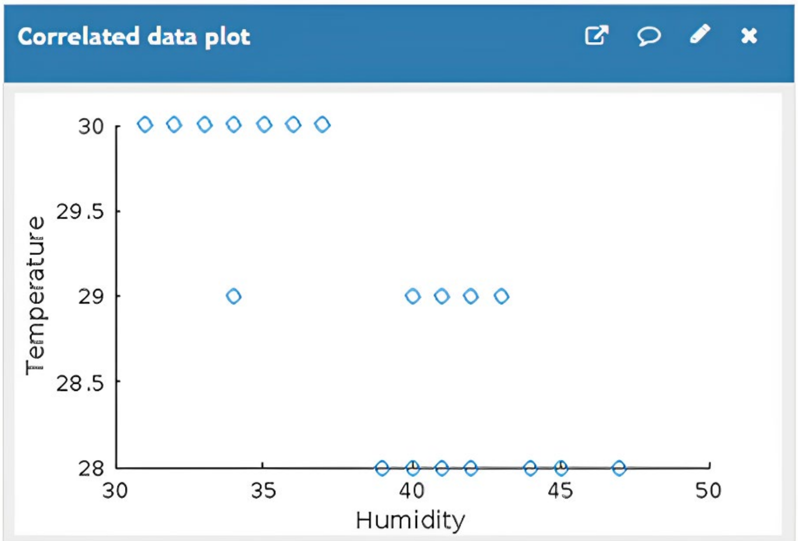


Fig. 9. Live data depicting the correlation between Temperature and Humidity.

6 Conclusions and Outlook

In this study beyond the bibliographic investigation regarding the energy democratization, a smart grid framework has been proposed and applied in a university campus. Ultimately, the purpose of the presented research work is to lay the foundations for transforming traditional consumers (including organizations such as universities), in becoming prosumers. Finally, on the basis of demand response (DR), the key challenges and opportunities for future development have been extracted and presented in Figure 10. Decentralized aggregation markets or peer-to-peer trading may be the future, but they have mainly been tested in small-scale projects and their lasting value remains uncertain. New technologies, like blockchain, increase the possibilities of implementing local and retail market mechanisms, making consumer objectives more attractive. This section outlines future trends and outlooks for DR policies for prosumers. It covers barriers that decisionmakers must overcome and opportunities and recommendations. Figure 10 shows areas for research and possible barriers and opportunities for different market players. The section discusses parameters for analyzing barriers and opportunities at four levels and provides an overview of DR programs and optimization techniques.

Similarly, in Figure 10, the domain for the democratization of energy is presented. Upon further examination of the figure, the four sub-domains can be utilized in order to highlight the key areas providing fertile ground for future research, namely i) prosumer, ii) aggregation and community, iii) market regulation, and iv) independent system operator.

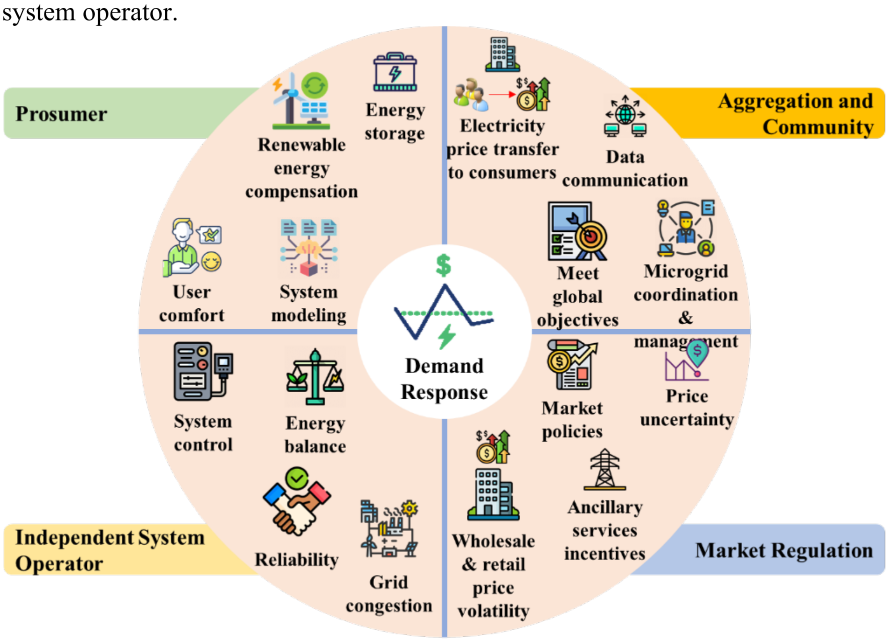


Fig. 10. Overview of key challenges and opportunities in the democratized electric energy market [44].

Prosumer: Prosumers can generate electricity and participate in the market. To overcome barriers, opportunities include using Battery Energy Storage Systems (BESS) and DR programs, developing intelligent technologies for real-time monitoring and implementing Home Energy Management Systems (HEMS), and improving mathematical models of electrical appliances.
Aggregation and Community: Current research has identified aggregators coordinating with community energy markets, but more attention is needed to create business and asset management models using DR programs and optimization, assess feasibility of migrating to participate in community electricity markets, and develop hardware and software with advanced algorithms for DR integration and optimization.
Market Regulation: To improve market regulation, more research is needed to investigate the relationship between DR programs, prosumer optimization models, and market regulation. Key considerations include utilizing DR as ancillary services, evaluating the impact of DR on price regulation, investigating legal issues related to selling surplus energy, and developing public policies to balance markets. Mathematical formulations can aid in pilot project construction, market modeling studies, and evaluation of opportunities for aggregating agents. Different business models may be applied depending on the region, and small-scale users have an incentive to engage in DR programs where allowed.

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The Importance of "Loss and Damage" in Supporting Climate Policy Debate

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Abstract. Undoubtedly, climate change has profound impacts on human and natural systems. In recent years, there has been a growing recognition of the need to address the Loss and Damage issue, which is associated with the adverse effects of climate change, particularly in the developing countries which are more vulnerable to its impacts. In this context, there is a wide range of studies examining the concepts, resilience, adaptation and policy options for dealing with climate change losses and damages. In this spirit, the present paper discusses actions, research and financial needs, as well as some adaptation, stakeholder engagement, governance and risk transfer issues related to Loss and Damage.

Keywords: Loss, Damage, Climate, Impact, Policy

1 Introduction

Climate change is one of the greatest challenges the world faces today, with far-reaching impacts on human and natural systems [1]. A major impact of climate change - mainly caused by the emissions of developed countries - is that developing and least developing countries are facing much more effects, thus making them more vulnerable to climate change associated disasters such as flash floods, heat waves, droughts, depleted reservoirs, forest burns etc. [2]. This is where the concept of Loss and Damage (L&D) arises, which refers to the negative impacts of climate change that occur despite, or in the absence of, mitigation and adaptation [3]. In this context, at the United Nations Climate Change Conference (COP26) in Glasgow [4], activists and representatives from the most affected developing nations demanded compensation from developed countries for the losses and damages that can be directly linked to their emissions levels which can't be stopped through previous mitigation strategies. They aimed at providing political space to discuss the credibility of support for loss and damage, and securing meaningful outcomes for COP27, and also paved the way for rebuilding trust between developed and developing countries [5].

The debate on L&D has gained traction over the last years and is continuously supported by growing scientific and empirical evidence on exploring the effects of climate related hazards and their impacts [6]. Especially, the notion of disproportionate impacts on certain communities and regions has long been a part of policy debates and the policy agenda in the international negotiations on climate change. Yet, disproportionality remains relatively undefined and implicit regarding L&D [7]. Disproportionality is a central and contentious issue within the international negotiations on climate change. It is instrumental regarding the emergence of L&D as a concept and political debate issue in global policy processes, which aim at addressing the losses and damages that are associated with the impacts of climate change. A coherent theoretical basis of disproportionality is necessary towards advancing science and policy on L&D. In this context, some critical questions need to be asked before delving into the L&D policy debate: what is disproportionate, to whom, and in relation to what?

The L&D debate encompasses a broad range of topics, including research, action, finance, and methodological approaches. Current research pathways seek to understand the nature and extent of L&D impacts and identify effective ways to address them. Action on L&D involves implementing measures to reduce the impacts of climate change and support the affected communities. Financing L&D is also critical as it requires significant resources to address the impacts of climate change on vulnerable communities. Approaches to L&D include adaptation, stakeholder engagement, governance, and risk transfer, among others. Current approaches aim to address L&D issues through various means including, among others, resilience enhancement, capacity building, community-based initiatives support, improvement of information access, and financial assistance provision.

At COP27 conference, a breakthrough agreement was reached to establish a new L&D fund in order to help vulnerable countries to cope with the devastating impacts of climate change. This fund is going to provide financial assistance to countries that suffer from climate related losses and damages, such as extreme weather events, sea levels rise, and other climate induced disasters. The agreement recognizes the urgent need to address the issue of loss and damage, particularly for countries that have least contributed to the problem. The fund is expected to start operating from 2024, and it is hoped that will help to mitigate the worse impacts of climate change on vulnerable communities and support their adaptation efforts [8]. The present study aims to provide a comprehensive overview of the L&D discourse by highlighting the current state of research and action on L&D, as well as the financing needs and approaches to address it. By examining these topics, this paper seeks to shed light on the challenges and opportunities that lie ahead in addressing this critical issue.

The rest of the paper is organized as follows: In Section 2, there is a brief history of L&D issue. In Section 3, approaches to cope with L&D are discussed, while, in Section 4, responses to L&D are presented. Finally, in Section 5, the things that need to be done are discussed, while in Section 6 conclusions are drawn.

2 Historical Overview

Climate related impacts, in their various forms, will increasingly affect livelihoods. The discussion on how to best address the permanent and irreversible impacts of climate change has been a subject of consideration in the climate regime since its very beginning. The concept of "Loss and Damage" and its connection to insurance tools and approaches has been traced back to a suggestion put forward by the Alliance of Small Island States (AOSIS) in 1991 during the negotiations of the United Nations Framework Convention on Climate Change (UNFCCC) [9]. AOSIS, a recently formed coalition of small island nations, proposed the creation of an international insurance pool as a means of collectively sharing losses and compensating the most vulnerable small islands and low-lying coastal developing countries for the damages they experience [7]. The idea of insurance was raised again at COP7, which held in Marrakesh in 2001 [10], and at the discussion took off in 2007/2008 [11], where a mechanism to address L&D was proposed, consisting of three interdependent tracks: an insurance element, to help vulnerable developing countries manage financial risk from increasingly frequent and severe extreme weather events; a rehabilitation and compensation part, to address the progressive negative impacts of climate change such as sea level rise and increasing land and sea surface temperatures; and a risk management component [12]. The global community acknowledged in 2013, through the implementation of the Warsaw International Mechanism [13], that human-induced climate change will cause a variety of negative consequences, even with efforts to lessen its impact and prepare for it. At COP21, that was held in Paris [14], loss and damage was included in article 8 of the Paris Agreement, in a stand-alone article that was separate from adaptation. L&D, associated with climate change, has emerged as one of the most important issues needing urgent attention both at local and national levels for a number of reasons [15]. Important factors related to L&D are the barriers towards reducing the greenhouse gas (GHG) emissions, as well as the limitations in scaling and the ability to maximize the effective adaptation.

L&D plays an increasingly larger role in the international climate change negotiations and in the national level climate change policies, as has been evidenced both by the prominence recorded in the Glasgow Climate Pact and the growing number of references in Nationally Determined Contributions (NDCs). To align L&D policy with mitigation measures, various researchers, as well as policy makers, of the Global South focus on liability and compensation mechanisms. Yet, countries in the Global North have considered L&D as a red line, while the UNFCCC had ruled out any avenue for liability and compensation [9]. Under these circumstances, its ambiguous nature will continue to make difficult the finding of a solution that works well for both sides.

3 Loss and Damage and Related Approaches

Most of the existing literature has focused on loss and damage that has already occurred, in the sense that there are already on-the-ground impacts from climate hazards [9, 16, 17, 18]. The first studies on loss and damage, related to climate change, appeared in the last decade, while there is a plethora of studies coming from other disciplines such as disaster mitigation and risk management. Especially, in the context of climate change policy, there has been a significant increase in studies by 2013. From the outset, this plethora appears to be quite motivational, given the absence of studies (particularly those that are based on empirical research) to support the international policy debate.

In this particular context, there are four primary categories of evidence used for weather attribution, as discussed in [9, 48]. These categories include: (1) physical reasoning, which involves examining whether a weather event aligns with climate trends; (2) statistical analysis, which assesses if an extreme weather event falls outside the range of what would be expected in a climate unaffected by external influences; (3) fractional attributable risk, which utilises climate models to compare the likelihood of a specific event occurring with and without climate change forcing; and (4) a more philosophical approach that argues that, since climate change is an established scientific reality, all climatic phenomena are influenced by climate change. Most empirical case studies tend to adopt either the first or the last approach, implying that climate change is acknowledged and, consequently, all extreme events should be considered as instances of climate change-related loss and damage.

Regarding vulnerability, its presence is not only a result of visible formal governance mechanisms but also due to informal and invisible governance processes that shape daily life in many of the places disproportionately affected by extreme and slow-onset events. While climate change is a current and unfolding reality, it is important to consider and portray these vulnerability processes within a historical socio-political framework, as they can materialise as L&D in the affected communities [19].

Climate change has been labelled as a human rights challenge of the twenty-first century and, in particular, L&D resulting from climate change poses a severe threat to the human rights of the affected communities. Human rights laws and approaches have potential to provide remedies in the field of climate change where other areas of the law do not apply. This concept has been broadly acknowledged in literature by [20]. Human rights protection approaches could empower victims as participants in the decision making process that concerns their lives and livelihoods and promotes cooperation between states and those that are most affected [21]. In this context, L&D can be operationalized when human rights guidelines for loss and damage policies and actions, as well as for conducting impacts assessments, can be developed, and a specialised body to monitor the compliance can be set up.

L&D has been conceptualised as a development crisis issue in order to emphasise the importance of taking a broader societal approach to climate change[22]. Until now, climate change has predominantly been an environmental problem, often neglecting the social, political, cultural and ethical dimensions of the issue [23]. By conceptualising climate change as a development crisis issue, opportunities for transformation to address the root causes of L&D are more likely to emerge. Transformation as liberation offers the widest range of policy opportunities for the broader policy framework of L&D to meet the goals of equitable and sustainable development. It also offers a set of potential factors and recommendations to help transform policy into practice, as well as to highlight the role of global processes in facilitating it.

While L&D is often associated to social approaches, it is important to recognise the critical role that science must play in addressing the challenges posed by climate change. Rather than simply focusing on compensation, L&D should prioritise the capacity building to manage risk. A thorough understanding of the root cause of L&D is necessary to establish a strong foundation for the ongoing negotiations. On the other hand, models used by climate scientists to estimate the probability of extreme weather events, resulting from anthropogenic climate change, can be very challenging due to their limitations and inability to simulate accurately such events [24]. Therefore, it is important to invest in scientific research and development to improve the accuracy of these models and better understand the complex interactions between human activity and the climate system. By doing so, the ability to mitigate the impacts of climate change and build more resilient communities will be enhanced.

4 Response to Loss and Damage

4.1 Governance

L&D governance consists of national risk management strategies, approaches, and tools, as well as formal policy mechanisms that address the residual effects of human-caused climate change, given that mitigation and adaptation efforts have failed. However, current global level policy mechanisms lack the jurisdiction to provide comprehensive L&D governance [19]. As a result, effective L&D governance is primarily embedded into national and international disaster recovery and risk management mechanisms.

Energy and climate policies, along with the production and growth model, depict the path that national economies follow against climate change. Sustainable development could indeed enhance mitigating loss and damage due to its ex-ante treatment of the problems. Of course, in developed countries, L&D is generally situated within the adaptation and disaster management approaches [25, 26, 27]. On the other hand, developing counties focus mainly on "beyond-adaptation" impacts [28, 29, 30].

4.2 Risk Transfer

As mentioned in [9], individuals typically prioritise insurance coverage for potential catastrophic events that could affect them or their property, often without any fault of their own. In this scenario, it may seem reasonable to expect countries in the Global South to pay insurance premiums for climate change impacts that they have not significantly contributed to. Setting temporarily aside any arguments about causation, when disasters occur beyond the capacity of national governments to handle, the international community often provides technical and financial assistance for the response. One potential solution could be to encourage all countries to contribute to an insurance pool, while recognising the principle of common, but differentiated, responsibility among individual states. This means that countries at greater risk, but with less financial capability, should contribute proportionally less, compared to countries at lower risk, but with greater financial capacity.

Numerous developed countries have supported risk mitigation and risk transfer strategies. For instance, US submissions frequently emphasise at risk mitigation and connect it to the requirement that a L&D policy needs also be considered as part of a continuous adaptation strategy [31]. Nonetheless, several parties have expressed trepidation regarding insurance solutions to L&D.

4.3 Adaptation and Coping

The policy remit of L&D, as well as its distinction from adaptation policy and practice, have been hotly debated, primarily along with two lines of inquiry: What should we think about? Only the impacts of today and future? Or both, along with the scope and the potential to avoid risks? Given the unpredictable and ever-changing nature of the global climate, adaptation will always be challenging. Research on the impacts of droughts from study sites in four African and Asian countries, that were surveyed in vulnerable communities, revealed that vulnerable households used a more diverse portfolio of coping measures [32]. Coping strategies are short-term responses to the impacts of sudden or unusual events. By contrast, adaptation refers to long-term adjustments to more permanent changes in the climate [33]. Beyond coping and adaptation, a third type of response involves the preventive measures (risk reduction) that households adopt in response to normal characteristics (including variability) of the climate and environment and the anticipation regarding unusual events [34].

The lack of technical and scientific information, and the capacity to use it at the local level is one of the most important barriers to adaptation [15]. This is why decision makers need to assess adaptation options in the context of climate change effects on the local community and infrastructure [35]. Therefore, engaging local stakeholders in discussions constitutes a challenge for policy makers.

The process of adaptation at various spatial and societal scales, and the achievement of long-term sustainability must be evaluated based on distinct criteria at these respective levels [36]. Moreover, concepts such as efficacy, efficiency, fairness, and validity are quite crucial in this context, but the degree of importance assigned to each criterion is not predetermined, but rather it arises from the consent and the actions of the societal processes. The degree of accomplishment depends crucially on the ability to adapt and the allocation of that ability. The importance of the criteria for success is debated and will vary over time [35].

4.4 Stakeholder Engagement

Stakeholders that are engaged in L&D issues have a clear, but diverse, understanding of its definition and how it could be mitigated. While there appears to be some agreement on L&D defined as the residual losses and damages after implementing actions, other stakeholders mention the need to apply more broadly based engagements, with L&D providing the impetus for stronger mitigation and adaptation outcomes. In order to mitigate, prevent, and remedy L&D, conversations regarding climate change risk and adaptation necessitate a focus on tackling the fundamental causes of vulnerability [19].

Climate change issues are being addressed through national and international level structured efforts. These are influenced by various stakeholders and hence their opinions impact the importance of issues under consideration [15]. International cooperation, in general, has not been proved very successful, especially when it comes to the issue of global commons, due to the conflict and asymmetry between countries that bear the cost of action and those who benefit from it [35].

5 What Needs to Be Done?

While L&D is a major and topical issue that concerns the world, yet there is lack of knowledge on national-level financing and effective mechanisms for managing it. Concerning actions, it is crucial to enhance support and capacity building, focusing especially on addressing L&D associated with the adverse effects of climate change. This will strengthen dialogue, coordination, coherence and synergies among relevant stakeholders. Although climate adaptation has been strengthened in the Paris Agreement, climate-related risks may exceed adaptation possibilities for communities and countries [36, 37]. Finding a framework that will be adopted by all parties is essential for the L&D negotiations.

The necessity to implement actions in various disciplines constitutes research as a critical catalyst. All related scientific fields are constantly met up in new developments, technologies, geopolitical interests and climate data. Study [38] provides a historical overview of the emergence and evolution of the concept of L&D within the UNFCCC, and analyses the different frames and discourses used by various agents in order to shape the debate around this issue. They argue that the framing of loss and damage, as a legal and political issue, has significant implications for the negotiations and the actions taken to address the impacts of climate change. Emphasis is placed on topics such as adaptation, policy and governance, but, as pointed out in [2], anthropogenic climate change is going to engage further the global community.

Regarding especially the adaptation, resilience should be viewed as a dynamic process rather than a static condition [39]. Regional differentiation is important for assessing both future climate risks and the different vulnerabilities of communities to incremental increases in global mean temperature [40]. In this context, the following three concerns are listed in [41]: (a) scale, interconnectedness and speed of climate change, which are believed to create a limited window for action on adaptation, (b) adaptive capacity will not necessarily be translated into actual adaptation, with multiple barriers potentially impeding adaptations across sectors and scales, and (c) the extent to which actions already in place are not sustainable, with maladaptation predicted to abound in multiple sectors.

Regarding policy and governance, a review on politics and how they have been understood within the realm of international L&D governance is provided in [42]. In addition, the policy space for addressing L&D is examined in [37], referring to the residual impacts that occur despite the adaptation and mitigation efforts, arguing that policy approaches must be tailored to address specific types of loss and damage, as well as the needs of vulnerable populations. Last, but not least, concepts, metrics and the governance of L&D, from four sustainable development perspectives, are examined in [43]: (a) Weak Sustainability, (b) Critical Capital Sustainability, (c) Wish List and (d) Human development. Moreover, the idea that sustainable development provides a coherent, comprehensive, and integrative framework for the further development of L&D scholarship and that human development is the most advanced perspective on sustainable development is also supported. Finally, progressive research should include both empirical and theoretical explorations of the potential for transformation, while understanding what people value and how they can engage with loss and damage [44]. This should not be skipped in order to ensure that the perspectives of the most vulnerable groups are indeed included in the decision making process, and that greater policy relevant research and critical analyses of L&D conceptualizations are taken into account.

Regarding financing for L&D [45], in developing countries where much of the population lives in poverty, extreme weather events can be a devastating blow [46]. Individuals have little savings to rebuild, while governments with few resources struggle to secure the millions of dollars needed to help communities recover from the effects of climate change. Although developing economies are mostly consisted of globally responsible citizens, they are also victims of the polluters, who have caused them to be hit hardest by climate change. While the importance of financing for L&D is agreed, for these vulnerable people who are the most affected by the challenges of climate change, there are divergent views on this, relating to historical responsibility and principles of equity. The types of funds, fair distribution and identification of who should receive financing, given disproportional L&D across nations, are a few of the existing challenges [19]. Undoubtedly, financing for addressing L&D is a way that wealthy countries need to follow. In this direction, industrialised countries need to commit additional funding, which is a quite crucial part of climate justice.

6 Conclusions

In conclusion, we realise that it is urgent for the international community to play a more active role in supporting policy makers to efficiently assess the impacts, as well as the scaling of loss and damage, which is experienced from human-induced climate change in different regions and in different national contexts, over different time frames and at different emission pathways. In this direction, it is crucial to work with stakeholders and decision makers in order to efficiently design and promote strategies that are suited to assisting the most vulnerable against loss and damage.

Since countries have established a fund, the hard work of designing and ultimately filling it has begun. Negotiators have formed a Transitional Committee to develop recommendations, which should be operationalised by COP28, along with the broader framework for funding arrangements, including funds and initiatives inside and outside the UNFCCC [47]. Furthermore, over the next period, countries are going to work on selecting the host organisation, electing members of the Advisory Board, and hiring the secretariat for the Santiago Network.

In 2023, there will be a focus on whether parties adopt a robust framework for the Global Goal on Adaptation and fulfil their financial pledges to the Adaptation Fund, Least Developed Countries Fund, and others. There will also be attention on whether progress is made towards doubling adaptation finance and if adaptation efforts are scaled up. Additionally, the accessibility of these funds and their reach at the local level will be closely monitored. Developed countries' commitment to providing $100 billion annually to developing countries will also be scrutinized, with attention on whether they accelerate their pledges to compensate for previous shortfalls. Negotiations will continue on the details of the new climate finance goal, including the quality of funding, timelines, instruments, sources, and access, with the aim of establishing it in 2024 [47].

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The Development of the European Union State Aid Rules in the Energy Sector

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Abstract. The paper presents the developments on the framework that governs the investments on the energy sector, focusing on competition law and the support to renewable energy sources through state aid. The researchers examine the developments of the state aid cases that have been under assessment by the European Commission over the course of the years and particularly, those regarding investments on renewable energy sources (RES) after the announcement of the European Green Deal, in late 2019. In addition to the above, the decisions of the European Commission and its general tendency to not raise any severe objections against such cases of support schemes provided as state aid, are reviewed in parallel to the energy policy of the European Union, as it has been recently shaped in order to promote the use of RES in the EU. Besides, the increased penetration of RES for the European Union, bares multiple benefits since, apart from playing a key role in the Union's policy to tackle climate change and its severe consequences, it also contributes in the extended efforts of the EU Member States to minimize their dependence on energy products highly imported from Russia, such as natural gas, in the shadow of the recent war in Ukraine. Under that prism, the paper provides a coherent and consistent examination of the ways in which state aid can be accepted by the European Commission, within the broader EU framework on Competition. Thus, the key findings of the paper showcase that when the support, in the form of state aid, is provided to promote the development of activities that serve the common interest of the EU Member States, the support schemes are mostly accepted to be implemented. Such activities that serve the Union's common interest are – inter alia – the activities that support the energy transition as well as the environmental protection within it and lead to the energy independence of the EU as well, as it will be further analyzed in this paper.

Keywords: competition law, energy investments, European Commission, European Union, state aid, support schemes.

1 Introduction

State aid as it has been defined by the European Union and the legislative framework governing it – which will be further discussed following in this paper – is the advantage provided in any form by the state, its national authorities or/and its budget, to undertakings in a selective manner. More particularly, state aid has been addressed within the framework of the European Union legislation, basically under the Treaty on the Functioning of the European Union (TFEU) and Articles 107, 108 and 109 of it. The provisions of these articles provide the exact definition of what kind of support constitutes state aid, as well as the criteria that if met, can make the support schemes compatible with the internal market rules. In that sense, Article 107 specifically foresees that "any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favoring certain undertakings or the production of certain goods shall, in so far as it affects trade between Member States, be incompatible with the internal market" [1][1].

At this point, it is useful to take into consideration the definition and the notion of the internal market, as provided within the European legislative framework. In particular, Article 26 of the TFEU while highlighting that "the Union shall adopt measures with the aim of establishing or ensuring the functioning of the internal market, in accordance with the relevant provisions of the Treaties" it is further developed by defining that "the internal market shall comprise an area without internal frontiers in which the free movements of goods, persons, services and capital is ensured in accordance with the provisions of the Treaties[2]" [1][3]. Having this noted is important in order to understand that most of the economic sectors within the European Union have been liberalized under this prism, with the sector of energy also included in the above. However, apart from the notion of the internal market as described earlier in the form of a single market, the European Union has proceeded further by adopting a policy that emphasizes the sustainable development of this market. In that sense, provisions of the Article 194 of the Treaty specify that "in the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in the spirit of solidarity between Member States, to: ensure the functioning of the market; ensure security of energy supply in the Union; promote energy efficiency and energy saving and the development of new renewable forms of energy; and promote the interconnection of energy networks" [1][4].

In the light of the above, the European Union seems to emphasize on the need for environmental preservation and its broader improvement, while at the same time, it is noted that such a necessity should be supported by the Member States in ways compatible to the internal market rules. Further examining the above, the results could lead to the consideration that those two elements are contradictory to each other. Thus, it could be considered that the support which is often necessary to be provided by the Member States to undertakings related with the development of renewable energy sources, in order to contribute in the environmental preservation, despite its importance often violates the state aid rules – and the rules of the single market - as it is mainly based on rather selective national support schemes.

To elaborate, specific measures that are adopted by the EU Member States in order

[1]TFEU Articles 107-109
[2]The Treaty on the Functioning of the European Union and the Treaty establishing the European Community
[3]TFEU Articles 26
[4]TFEU Articles 194

to achieve the energy transition targets or the climate neutrality targets that the European Union has set, often concern aid schemes granted to particular entities that can contribute in this, even though they may create selective advantages and distort competition. Such measures and aid schemes are going to be examined in detail later in this paper through an overview of indicative state aid cases that have been approved by the European Union despite the competition risks.

Under that prism, this paper provides a holistic coherent overview of how state aid might affect competition, according to the EU and a parallel overview of how the European energy policy has been evolved, prioritizing the energy transition and setting goals as ambitious as having a carbon neutral economy in the Union by 2050. These overviews, even though they might seem irrelevant on a first level, when set together and through the particular cases used as examples in the last part of the paper, they showcase what the paper aims to prove; that the swift on the EU policy towards emphasizing in the green energy transition often allows the European Commission to keep a less strict attitude when deciding whether to accept state aid schemes on renewable energy or energy efficiency investments to be implemented by a Member State or not.

Furthermore, Article 107 also specifies the conditions under which providing support to undertakings can be considered as compatible with the rules governing the internal market. In particular, the respective provisions specify that the types of aid provided, in order to be accepted under the state aid rules should serve a social purpose; be provided to consumers on individual scale; as well as to be given in a way that the origin of the products involved remains irrelevant; and should be granted in order to contribute into overcoming damages resulted by extreme occurrences, weather related incidents included. Following, additional criteria are developed, by the same Article, setting the conditions under which, aid, other than the types of aid mentioned above, can also be considered as aligning with the rules of the internal market. More specifically, aid provided in the form of state aid- as already described - can be considered compatible with the internal market on condition that it supports the promotion of economic development for regions in which living conditions and standards are extremely bad and which are characterized by severe underemployment, as well as for those areas listed in Ar. 349 of the Treaty, considering their structural, financial or social conditions; it promotes the development of a crucial PCI (meaning the projects listed by the European Commission as Projects of Common Interest for the European Union), or it contributes to correct important troubles in the economy of a Member State. Moreover, in accordance with the same provisions, aid provided as state aid, can be compatible with the internal rules if it promotes and facilitates the development of specific activities or fields of the economy of a Member State, while it does not cause immediate impacts on the trading conditions at a level surpassing the significance of the common interest. As an extent to the above, state aid might also be accepted as compatible to the rules of the internal market when it is granted to support the conservation of culture and heritage of a Member State, on condition that such aid, similarly, does not affect trade in ways and severity that overcome the value of the common interest. Following these, it is provisioned that additional types of aid can be defined by decisions of the Council upon a respective proposal by the European Commission [2], [3].

Apart from the above, within the provisions of the TFEU, in Article 108 important procedural conditions are laid down regarding the granting of aid. According to these, the European Commission needs to be in constant cooperation with the Member States in reviewing their aid providing systems adequately and to provide suggestions to these States on how to adjust, by adopting the necessary measures, on the developments concerning the proper function of the single market. Other than that, it is also provisioned that the Commission has to be notified well in advance, by the Member States, regarding any plans to provide new support in the form of an aid scheme or to alter an already existing one. Following the notice, the Commission shall reach a decision on the compatibility of the proposed measure, prior to which the State shall not put it into effect. Finally, Article 109 of the TFEU foresees that particular regulations may be developed by the European Institutions on the application of the Articles mentioned above [1].

2 The Criteria of Article 107

The importance of state aid and its control of the preservation of proper conditions of competition is highlighted along the relevant European legislation. What has been characteristically noted on this, in the Report on Competition Policy, 2010, drafted by the European Commission is, inter alia, that control on state aid has grown to be a crucial part of the single market, by safeguarding that corporate undertakings can compete each other on fair terms regardless of where they are based; as well as that Member States are not engaging in subsidy races burdening each other or the common interest of the European Union, which would result in a waste of resources and threaten the cohesion of the Union in general [4].In the light of the above it is important to examine the criteria set by Article 107 regarding the compatibility of state aid in order to avoid cases where the competition might be distorted due to state intervention in the market.

More specifically, on the basis of the provisions of Article 107, paragraph 1, as explained above, it can be concluded that the article initially provides a negative condition concerning the plans of the Member States to provide aid in order to serve particular purposes, excluding the occasions laid out in paragraphs 2 and 3 of the Article [5]. These exceptions are usually applied in a further processing stage of the assessment of each scheme's compatibility, after being reviewed under the main four criteria set by Article 107, par. 1, that constitute such aid incompatible to the rules of the internal market in the first place, as they will be presented below. The four criteria on the state aid, spotted through these provisions, are as such:

A. Granted through State Resources or by the State

First of all, Article 107, par. 1 notes that "any aid granted by a Member State or through State resources […]" shall be considered as incompatible with the rules, setting a quite broad definition where confusion might arise regarding what is included in the State or the State resources. Through a long collection of the European Commission's decisions on state aid – some of which will be indicatively presented in the following parts of the current paper - it has been concluded that all state authorities, included local or regional ones shall be included in the above provision, while as far as the state resources is concerned these have been found to include direct funding from the state budget, as well as indirect financial support in the form of tariffs, taxation related measures and more [6], [7].

B. Economic Advantage

In addition, for a support scheme to constitute state aid incompatible with the rules of the internal market, the beneficiaries of the aid need to be granted particular economic advantages which would not be provided to them in absence of the support. On top of that, it is noted that in order for an undertaking to be in position of receiving such an advantage, it shall be any natural or legal person that executes economic activities of particular regularity and duration, no matter its legal status or the means by which it is supported [8]. Besides, considering that the aid provided to an undertaking will be provided directly or indirectly through the state budget, it is obvious that the economic support it will receive is going to place it in an advantageous position [9].

C. Selectivity

Following the above, the criterion of selectivity is quite important in the assessment of support provided as state aid because the beneficiaries involved receive advantages that are not accessible by other similar or not undertakings often operating in the same sector. In other words, the state's intervention is considered illegal when it benefits specific undertaking or the production and promotion of particular goods more than it benefits others. However, should the intervention be inclusive for all undertakings and activities indistinctively, the legality of it would not be under such consideration. Consequently, it seems that the legality of the state support and the selective character of it, regarding the advantages it provides, cannot be considered compatible, unless the support scheme falls under the exceptions foreseen in the following points of Article 107 [9, pp. 103-150].

D. Effects on Trade and Competition Conditions

As it is expected, since the internal market has been developed in a way that operates commonly beyond the borders of the Member States, the benefits provided under the state aid schemes have high potential to impact the trade conditions between these Member States, as well as the competition conditions in general. However, due to the fact that the distortion of competition is often challenging to be clearly proved, when assessing state aid cases under the prism of this criterion it is enough to examine the level at which the measure even threatens to distort competition. In addition to that, when assessing such support schemes, the European Commission also needs to provide adequate reasoning that they affect the trade within the Member States, no matter the size of either the aid or the beneficiary. Besides, considering that the undertaking benefited by the aid is active within an existing and liberalized market, such as the integrated electricity market is, this criterion is highly possibly met [10].

E. Exceptions of Paragraphs 2 and 3 of Article 107

Following the above mentioned criteria, which if met cumulatively, the state aid is considered to be incompatible with the internal market rules and thus illegal, several occasions of state support are excluded by the prohibition of the Article 107 on the basis that such aid serves particular purposes, necessary for either the protection of an area in need, or the development of particular activities that highly contribute to the support of the common interest of the European Union and its Member States, regarding various economic sectors. An important example of activities related to the common interest of the Union and its Members States, especially under the recent developments either regarding the climate crisis or related to the developments in the EU energy sector, are those activities dedicated to tackle climate crisis and its consequences or to safeguard the security of energy supply for the European Union.

3 The European Energy and Climate Policy and the State Aid

The European Union has developed significantly the common policy adopted internally in order to adjust its climate targets, increase its climate ambitions and align with the most recent developments. At the same time, the severity of climate crisis and its consequences, along with the risks related to the Union's energy security have escalated making these issues be included in the top priorities of the European policy [11]. Under that prism, the European Commission announced in late 2019 the European Green Deal; a set of proposals laid out across several important policy areas, which aims to support Europe in becoming climate-neutral by 2050 and to succeed in fully decoupling economic growth from the use of resources. More specifically, in the process of reaching this target, emphasis is put on enhancing the economy while improving people's quality of life and taking care of the natural environment. Hence, the EU Green Deal constitutes a roadmap to govern the transition of the Union into a more sustainable future, which presents the current challenges as opportunities in the policy areas it includes, in a way that will be inclusive for everyone. The policy areas included in the EU Green Deal are Biodiversity; Farm to Fork Strategy; Sustainable agriculture; Clean energy; Sustainable industry; Building and renovating; Sustainable mobility; Eliminating pollution; and Climate action [12].

Following the above and within the framework of the European strategy as laid out by the EU Green Deal, the European Commission presented shortly after the "Fit for 55" Package. Thus, in July 2021, the Commission adopted a set of measures to make the European policies on land use, transportation, energy and taxation, inter alia, align with the revised and more ambitious targets of reducing GHG (greenhouse gas) emissions by minimum 55% by the end of the decade, in comparison to the respective emissions of 1990. These proposals brought together the development of the existing EU Emissions Trading System with the application of a respective system on additional sectors, along with measures for the increased use of renewable energy sources and the enhancement of energy efficiency, among others [13].

Indicatively, the new package, regarding the already existing EU ETS, includes proposals on the gradual seizure of free emission allowances in the sector of aviation and that the ETS should be aligning with the CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), as well as the inclusion of the shipping sector in the system too. In the same spirit, the Commission proposed a new ETS to apply on the sectors of road transportation and buildings too. In addition, it includes proposals on the revision of the Renewable Energy Directive (Dir. (EU) 2018/2001) and the Energy Efficiency Directive (Dir. 2012/27/EU) in order to increase their respective targets to 40% RES in the Union's energy mix by 2030 and 3% of the buildings of the public sector to be renovated on an annual base accordingly. Additional proposals of the Package include measures on the use of fuels in aviation and maritime, on energy taxation, as well as on the establishment of a carbon price on imports from non-EU countries.

In parallel, the European Commission, in order to increase the dynamics of the previously mentioned measures, proceeded to the first European Climate Law (Regulation (EU) 2021/1119) which practically wrote into law the targets set by the EU Green Deal and the EU Fit for 55 Package, aiming to make the European economy climate-neutral by mid-century, 2050, and to achieve the reduction of the GHG emissions by 55% until the end of the current decade (2030), in comparison to the levels of 1990. In total, the law focuses on safeguarding that all the European policies shall contribute to the above, as well as that no economic or social sector is excluded from the process [14].

Following these, the European legislative framework that shapes the broader rules on the state aid [15], includes provisions within several of its texts, which facilitate the granting of state aid as an exception to the prohibition of Article 107, on specific conditions. Initially, such a legislative text is the Council Regulation (EU) 2015/1588 regarding the application of the provisions developed in Ar. 107 and 108 of the TFEU and the first article of it, where several categories of aid – included this in favor of environmental protection – can be considered as compatible with the rules of the internal market without being obliged for the prior notification requirements of Art. 108, par. 3 of the Treaty [16].

Additionally to this, the Commission Regulation (EU) 651/2014, which declares particular categories of aid as complying with the internal market, provides a set of definitions that apply on such aid provided for environmental protection, starting with the very "environmental protection" defined as "any action designed to remedy or prevent damage to physical surroundings or natural resources by a beneficiary's own activities, to reduce risk of such damage or to lead to a more efficient use of natural resources, including energy-saving measures and the use of renewable sources of energy", followed by several energy related definitions such as energy efficiency; energy efficiency project; high-efficiency cogeneration; renewable energy sources; energy efficient district heating and cooling; energy infrastructure and internal energy market legislation, among others [17]. Within the framework of the above, the Regulation 651/2014 also includes – in its section 7 and the articles 38 to 48 of it – the provisions that set the conditions necessary to be met for investment and/or operating aid to be considered compatible with the rules of the internal market, on the fields of energy efficiency measures; energy efficiency projects in buildings; high-efficiency cogeneration; promotion of energy from renewable sources; promotion of electricity from renewable sources; promotion of energy from renewable sources in small scale installations; energy efficient district heating and cooling; energy infrastructure; as well as for the aid in the form of reductions in environmental taxes [17].

Then, an additional regulation, prior to the ones mentioned above, the Commission Regulation (EC) 794/2004, as amended and in force, is important to be mentioned, since its Chapter III governs the monitoring of the state aid policies of the Member States through the relevant annual reports its provisions foresee. In that sense, it is noted that every Member State shall, under the current provisions, provide its annual reports to the Commission in due time and the Commission in its turn, shall publish a state aid synopsis that shall include the information provided in the separate reports compiled. In the light of these provisions, the European Commission publishes on an annual base the "State aid Scoreboard" resulting from the expenditure reports submitted by the Member States [18].

The State aid Scoreboard is a key tool of the European Commission to showcase a State aid synopsis of the situation regarding the state aid measures in the Member States. Its issuance is based on the Article 6 of the Commission Regulation (EC) 794/2004 on implementing Council Regulation (EC) No 659/1999 laying down detailed rules for the application of Article 93 of the EC Treaty and it aims on providing a publicly available platform of information on the current state aid conditions across the EU and the control mechanisms the Union has for the state aid schemes. In that sense, the Scoreboard acts as an important tool for keeping track of the potential effects of the major policy developments in the field of State Aid. Thus, the focus points of the latest edition of the State Aid Scoreboard (2021) concern schemes related to the COVID-19 pandemic crisis and schemes related to the energy transition and the environmental protection, among others. [19]

The methodology used for the Scoreboard includes the examination of the Member States' expenditure for state aid measures that benefit specific industries, while it does not consider any cases for which decisions have not been made. In addition, it does not include any cases related to aid provided under de minimis rules; without favoring specific undertakings or sectors and without threatening to distort competition within the EU market. Further, the Scoreboard, makes a special reference to policy developments amongst which it includes the revision of the State aid rules with the guidelines on State aid for climate, environmental protection and energy (CEEAG) and the Temporary Crisis Framework for State Aid measures to support the economy following the aggression against Ukraine by Russia [19].

Under the prism of the above, the tendency depicted in the Scoreboard for the granting of state aid on the objective of environmental protection and energy savings, shows that this has been the primary objective for five EU Member States (Belgium; Czechia; Finland; Croatia; and Sweden) while it has been among the top 3 of the state aid objectives for the majority of the rest of the EU (28, UK included) Member States, such as Austria; Germany; Denmark; Estonia; France; Greece; Ireland; Lithuania; Luxembourg; Malta; the Netherlands; Romania; Slovenia; Slovakia; and the UK. On top of that, state aid on environmental protection and energy savings, according to the State Aid Scoreboard, seems to account for 20% of the total expenditure for the EU, in 2020. [19]

4 The Guidelines on State Aid for Climate, Environmental Protection and Energy

On top of the above, the European Commission has adopted a set of guidelines, which has been kept up to date with newer versions of it replacing the previous ones, regarding the state aid provided for reasons related to environmental protection and energy (EEAG). In that sense, the latest version of the EEAG, the "Guidelines on State aid for climate, environmental protection and energy 2022" continues to provide support on such aid following the prior set of "Guidelines on State aid for environmental protection and energy 2014-2020". In the first place, the scope of the 2014-2020 guidelines was to apply on state aid provided for environmental protection and the achievement of energy objectives in sectors such as transport, coal, agriculture, forestry and fisheries, unless otherwise defined by particular rules [20]. These guidelines, as expected, have been greatly taken into consideration in the cases of state aid examined by the European Commission over the latest years and have played significant role in the Commission's decisions not to raise objections against several state aid schemes.

Furthermore, the guidelines provided a simpler framework regarding the assessment criteria compared to the ones established by the previous edition of guidelines, especially on the topics of energy efficiency and cogeneration. What is more, the 2014-2020 guidelines excluded the issue of state aid on nuclear power projects establishing that it shall therefore be examined on a case-by-case level. In addition, in order for the European Commission to assess a measure of state aid regarding its compatibility, it shall examine whether the positive impacts on trade are more and of more importance than the potential negative effects on that. To do so, the guidelines provide several criteria that have to be met, in order for a measure to be considered lawful, among which that the measure should contribute to the objective of a PCI; that it needs to bring improvements which cannot be brought in the market if the measure is not provided; that it must have an incentive character; that it needs to be aligning with the principle of proportionality; that it has to be appropriate and transparent; as well as that it shall not cause undue negative impacts on the competition. Then, as far as the support on renewable energy sources is concerned, the guidelines foresaw that market instruments should be implemented in such a way that subsidies would be gradually reduced until minimized completely. Despite this, during the transitional phase towards this goal, state aid schemes on RES should be provided – according to the guidelines – for periods of maximum of a decade long and in the form of premium on top of the market price, where the beneficiaries would have to be under standard balancing responsibilities [21].

As an extend to that, the Guidelines on State aid for climate, environmental protection and energy 2022, proceed in replacing the previous set of guidelines having taken under consideration the EU Green Deal, the EU "Fit for 55" Package, as well as the proposals of these on the already existing European regulatory framework. Adopted in the beginning of 2020, the scope of the current guidelines is to apply on state aid measures used to support the development of particular economic activities in ways that boost environmental protection along with activities in the field of energy. Moreover, these guidelines shall apply on sectors that belong to EU state aid rules, unless these rules set otherwise. Further, the guidelines include a provision on the types of aid on which they do not apply, where among others, state aid for nuclear energy is included. Then, the kinds of measures covered by the provisions are laid out in the text. Among these, aid for cutting off GHG emissions; for supporting RES; for improving the energy performance of buildings; for promoting the use of clean vehicles; for incentivizing the transition towards a circular economy; for securing energy supply; for developing energy infrastructure and district heating and cooling projects; for providing discounts of electricity levies for the energy-intensive users; as well as for phasing out of fossil fuels are included indicatively. In addition, all the above-mentioned prerequisites on the principles of proportionality, appropriateness, necessity and eligibility that the state aid measure shall meet in order to be considered compatible to the state aid rules, are once again further developed [22].

5 Energy Related State Aid Cases and the Reasoning in them

Statistically, according to the data presented in the State aid Scoreboard of the European Commission for the year 2020, the country in which the biggest amount of state aid support was provided – as found based on the expenditure of 2019 – on projects under the category of "Environmental protection including energy savings" was found to be Germany by totally surpassing the amount of 36,000 EUR million in several support schemes, with others, such as France, Denmark, the Netherlands, Sweden etc. to follow with significantly lower amount of money provided through state aid schemes [19].

In this part of the paper, a short reference will follow to – indicatively - some of the state aid cases the European Commission has assessed and accepted since 2019, in order to present the main elements of these and the base on which the European Commission's reasoning is usually developed.

5.1 State Aid Case SA.55891 (2019/N) –Operating Aid Scheme for Electricity Generated by Incinerating Biomass in Existing and Fully Depreciated Biomass Plants in Denmark [23]

Under the state aid case SA.55891, the European Commission examined the Danish scheme which concerns the provision of a price premium to depreciated installations that generate electricity from biomass. Additionally, under the proposed scheme, the premium shall also be addressed to other existing biomass fired installations, which will be covering the additional operating costs of electricity production from biomass compared to the corresponding fossil fuels substitutes. The objective of the scheme is to contribute in increasing the level of the environmental protection in the country, since it was planned to contribute in achieving the national target of 55% of RES by 2030 and to complete the phasing out of coal for electricity production by the same year as well. Moreover, it will further contribute in achieving the EU target of at least 32% share of RES on energy consumption in 2030.

The beneficiaries of the scheme are a) depreciated installations generating electricity from biomass, b) existing non-depreciated biomass fired installations and c) a single plant that has been granted investment aid under the scheme SA.40397 (Support for the use of renewables in production processes in Denmark), while among the decisive criteria is that all supported installations must have used biomass before 1 April 2019 (the expiry date of the past biomass support scheme).

As assessing the measure proposed under the current case, the European Commission noted that the measure is selective, considering that it is granted only to subsector covering electricity production from biomass without being accessible for other electricity producers or other sectors of the economy. In addition, it was found that it derives directly from the state budget of the country, which means that it is financed through State resources. In the light of the above, the Commission noted also that the measure is likely to distort competition and affect trade between Member States; considering that as an advantage it is granted to producers of electricity from biomass who are engaged in transnational trade within the framework of the liberalized European electricity market. However, when examined under the prism of serving the common interest; under the level of necessity it is characterized with, as well as its alignment to the principle of proportionality, the Commission considered that the scheme aims at well-defined objectives of common interest, supporting the environmental protection by promoting the deployment of renewable energy, while it also provides an incentive effect, if it is taken into account that the premium induces the beneficiaries to change their behavior by enabling them to produce electricity from biomass. In that sense, the Commission decided not to raise objections to the aid on the grounds that it is compatible with the rules of the internal market.

5.2 State Aid Case SA. 53525 (2020/N) – The Netherlands SDE+++ Scheme for Greenhouse Gas Reduction Projects Including Renewable Energy [24]

In the state aid case SA. 53525, the scheme under examination concerns the expansion of the already existing StimuleringDuurzameEnergieproductie (SDE+) aid scheme, which focuses on the support of investments in renewable electricity and gas and heat production. With the previously accepted aid scheme to reach its closing period at the end of 2020, the national authorities notified the European Commission for its updated version, considering the increased climate ambitions the country has adopted for 2030. This new version, the legal base of which lies on the Royal decree "BesluitstimuleringduurzameenergieproductieenKlimaattransitie" (SDEK), falling under the legislation on subsidies, not only foresees the duration expansion of the measure previously supporting the promotion of RES, but it also includes additional the measures on the GHG emissions reduction too.

More specifically, the measure's scope is to subsidize incentives for the beneficiaries to work on the GHG emissions reduction. According to it, all the RES technologies from the previous version of the scheme are included in this as well, with the additions of further technologies such as a broader prism of solar thermal and geothermal technologies, aqua thermal energy solutions and technologies of compost heating, on condition that they are complying with the relevant definitions set in the EEAG. Moreover, technologies on reducing the GHG emissions shall be therefore supported by the scheme, such as those related to managing waste heat or to carbon capture and storage (CCS), as well as projects under which fossil fuel inputs are going to be replaced by electricity. In the light of the above, the subsidies provisioned by the measure shall be accessible only to new installations or to those – already existing – where additional renewable heat or gas or new CCS equipment are going to be added.

As assessing the aid under the state aid rules, the Commission noted that it derives from state resources, since – similarly to the previous version of it – it is financed by the state budget. However, the Commission had been notified for the proposed expansion by the country's authorities in adequate time before its implication. Moreover, the measure seems to be contributing to the development of particular economic activities – those of the investments on the technologies described earlier – as well as to be necessary in order to support these activities in ways that also support the preservation of the environment. In addition, the measure was judged as both appropriate and proportionate in order to serve the above scope, while due to the fact that it includes a competitive bidding process, it is also considered to potentially cause limited negative effects on trade and competition conditions, with its positive ones clearly outweighing any risks and not jeopardizing the common interest. Thus, the Commission decided not to raise objections finding the proposed scheme to be compatible with the internal market rules.

5.3 State Aid Case SA.58181 (2020/N) –Tender Mechanism for the Phase-out of Hard Coal in Germany [25]

The support scheme examined under the state aid case SA. 58181 derives from the initiatives of the German state to phase out of hard coal. More particularly, the support scheme was introduced to facilitate the phase-out of hard coal powered electricity generation in the country and includes the carrying out of seven auctions that have been planned to encourage the early closure of hard coal-fired electricity generation and small lignite installations within the period 2020-2026. German authorities considered this as the most suiting policy tool, considering that the auctions allow the compensation for each installation to be determined on a competitive basis.

Moreover, the country has adopted ambitious climate targets such as becoming climate neutral by 2050 and reducing the economy wide GHG emissions before 2030, by at least 55% compared to the levels of 1990. In that spirit, the country has additionally set sector-specific targets which - for the energy sector - means the reduction of CO2 emissions from approximately 254 million tonnes CO2 in 2019 to maximum 183 million by 2030. Under the light of the above, the reduction gradually and the phase-out eventually of coal-fired power generation (including hard coal and lignite) is crucial for the country to reach these targets.

The legal basis of the support scheme derives from the Coal Commission's proposals - a body which has been appointed by the government to ensure social consensus on the energy and climate policy of the country – and the following to these, "Act on the reduction and termination of coal-fired power generation and on the amendment of other laws", or else "Coal Exit Act".

Furthermore, the installations eligible for the scheme's support as beneficiaries are those installations that use hard coal as their prior energy source and have, at the same time, a valid authorization to operate. In parallel, excluded from the support scheme are, inter alia, those installations that have already issued a binding closure notice or a binding coal combustion ban notice; those that have already been included either in the capacity reserve or in the network reserve and have also announced their permanent closure; as well as those that have already been awarded a compensation in a prior tender procedure under the same law or that have been ordered to close in accordance with the regulatory closure too. Notably, several installations located in specific areas (such as the federal states of Baden-Württemberg, Bayern, Hessen, Rheinland-Pfalz and Saarland) have also been excluded, though only from the first auction in order to contribute to ensuring security of supply.

Following the development of the scheme, the European Commission received several third-party submissions against the support it provides claiming that it would lead to certain installations phasing-out quite later as the auctions process would encourage loss-making plants to keep operating so that they can participate to the tenders. At the same time, some questioned the proportionality of the measure comparing it with practices followed in different European countries, while others also contested that the scheme's auctions are indeed planned in a competitive and non-discriminatory way. Germany, responded to all submissions supporting the necessity and transparency of the measure to the European Commission that while assessing the notified aid scheme reached the following findings.

Initially, the Commission noted that the measure clearly derives from State resources considering that the compensation amount paid to the winning operators from the auctions derives from the state budget. Further, it was noted that since the measure is addressed only to hard coal-fired electricity generation and small lignite installations, it clearly provides a selective advantage, while the phase-out of these also leads to electricity share being produced by other generators, which has the potential to affect the merit order curve and thus the wholesale electricity prices, threatening to distort competition and affect trade between Member States.

On the other hand, following the above, the Commission highlighted that the measure is considered to contribute to the development of certain economic activities, as well as to the efforts in order to achieve the climate targets of emissions cuts in both national and EU levels. Additionally, the Commission resulted in the view that the scheme is well designed to support the development of electricity generation from alternative sources, while handling successfully the risks related to security of supply, considering the measure as an appropriate instrument to this scope. Further, as the measure under examination facilitates the development of additional electricity capacity based on alternative and innovative technologies, other than the so far used hard coal and fossil fuels, it has great potential to bring positive effects in terms of environmental gains, which in total overweigh any risks accompanying it for negatively affecting the trade and competition conditions. Consequently, the European Commission, noting that the measure also serves the proportionality principle, decided not to object to it, considering it to be compatible with the framework governing the internal market.

5.4 State Aid Case SA. 57858 (2021/N) – Thor Offshore Wind Farm in Denmark [26]

The scheme under examination in the current state aid case, concerns the process of a tender on the design, building and operation of an offshore wind farm in Denmark, in the North Sea (Thor site), located 20 km away from the shore. The project includes, except of the wind farm, the offshore substation and the process of the connection to the grid to the point of connection in the shore. Its objective is that Denmark will be supported to achieve its national target of 55% of RES by the end of the decade, with the development of the farm, while it can also accelerate the process of phasing out from coal. Additionally, the project can also support the country – in the long run – to become less and less dependent on fossil fuels as well as to approach the goal of climate neutrality by 2050. At the same time, it can accordingly contribute to the respective goals of the European Union too.

The legal basis of the measure derives from the revision of the Act on Promotion of Renewable Energy (RE Act) and the Act on Electricity Supply that allows an amount of state aid to be provided as a payment within the caps in the two-way contract for the model that concerns the electricity generated by this offshore wind farm. On top of that, the revision was planned to be implemented as soon as the European Commission would approve the scheme and notify the country's authorities for this approval, in adequate time prior to the submission of the final bids for the project. Moreover, considering that the scheme includes a tender process open to all interested actors, the beneficiary could finally be any kind of undertaking, meeting the requested for the project criteria. In particular, the beneficiary would need, inter alia, to not be or have recently been in difficulty, to have fulfilled the repayment of any illegal aid it might had received in the past, to be capable of undertaking all the relevant balancing responsibilities, as well as to be willing not to initiate any processes prior to the granting of the aid. Additionally, the scheme includes aid that shall be provided in the form of a two-way CfD premium, on top of the price for the electricity sold on the market as the difference between the offered price and the reference price, for a specific period of time.

As examining the aid scheme notified by the Danish authorities, the European Commission noted that it derives from State resources since it is planned to be fully funded by the State budget. Moreover, the Commission concluded that it does offer a selective advantage to a specific beneficiary – whichever this might be after winning the tendering process – since this beneficiary is going to be granted additional support in the form of premiums paid on top of the market price. In that sense, the proposed scheme was found as likely to both distort competition and affect trade conditions between Member States. However, the Commission also resulted that the measure is going to contribute to the development of certain economic activities, which are not only beneficial in the national and EU levels but are also unlikely to be properly developed without the granting of the scheme's aid. Taking this into account, the support scheme seems to also provide incentivization, on the basis that the beneficiary will be supported to alter its behavior towards the development of electricity production from the particular offshore wind farm and will lead to increased investments in offshore wind energy production and their interconnections to the grid. As a result, the Commission found the aid to be aligning with the principles of necessity, appropriateness and proportionality, as well as to have higher potential of causing positive effects by both facilitating specific economic activities and promoting environmental protection, then it has to cause any negative ones in the trade and competition conditions, serving the EU's common interest. In the light of the above, the European Commission also decided that the aid scheme is compatible with the internal market rules.

5.5 Observations

In total, as overviewing the state aid cases that indicatively but quite representatively have been overviewed in this paper, it can be noted that among the cases the European Commission has assessed over the last years, most of the times the Commission finds the measure to fall under the four criteria of the Article 107 of the TFEU. Thus, the Commission concludes that the proposed schemes are mostly planned to derive from state resources, as well as to provide selective economic advantage to particular beneficiaries, while threatening to cause distortion on the trade and competition conditions. These are the main elements that are commonly found in such cases and have also been found in all the cases presented in the paper. In that sense, the Commission deeply examines the ways in which these state aid cases can cause negative impacts on the common EU market and the ways in which they can cause positive ones, in order to reach the decisions of not raising objections against them.

Thus, even though the cases indicatively presented above do constitute State Aid, the European Commission assessed them baring into account the "Guidelines on State aid for environmental protection and energy 2014-2020" and the ways in which these schemes are important and contribute to the development of particular economic activities regarding the development of Renewable Energy projects and the innovation on methods of decarbonizations. These economic activities and fields clearly serve the common interest of the EU and the EU Member States as they are connected to both the environmental protection policies of the EU and the energy security strategy of the Union.

Consequently, it has been recorded that the European Commission eventually accepts the granting of such measures, mainly on the grounds that they serve the common interest, contribute in the development of particular and important economic activities that could not have been as such developed in absence of the schemes, as well as that they are necessary for the enhancement of the environmental protection policy and the energy transition both in the Member States and the EU.

6 Conclusion

Having taken into consideration the framework on the State Aid as set by the European Union rules, the policy developments within the European Union; especially regarding the prioritization of the energy transition in a way that promotes the energy security too; as well as the indicative presentation of state aid cases that represent the tendency in the European Commission's State Aid Decisions, as developed in the current paper, it can be concluded that state aid plays a crucial role on the development of several policy areas within the Member States of the European Union. Most importantly, the key findings of the paper show that state aid is crucial for the development of those economic areas related to the investments on renewable energy and new technologies used in the energy sector and the decarbonization efforts, as well as to the environmental protection. In that sense, state aid measures seem to be generally accepted by the European Commission when they aim to support such fields and serve the common interest of the EU Member States, especially on environmental protection and the energy transition.

In addition, it has been showcased that the energy and environmental policy of the EU has been developing in a highly dynamic way leading the framework on state aid to follow this dynamic development accordingly. Under that prism, it is highlighted that the main policies regarding the energy efficiency, the use of renewable energy and the decarbonization of the energy sector are the ones pushing the relevant state aid guidelines of the EU to become more flexible in order to overcome policy implications like the ones included in the current paper.

This parallel development of the energy and environmental policy of the EU on one hand and the State Aid rules of the EU on the other, is expected to continue an ongoing course leading to new frameworks that will allow the energy shielding of the European Union.

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Revitalising Small Historical Villages through Social, Economic, Cultural and Energy Efficiency Assets

Italian Examples and Methodological Approaches

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Abstract. Cultural heritage and historical buildings, accounting for over 30% of the overall European building stock, need to be preserved as much as possible, on account of their role in representing the cultural identity of a community, and to be renovated in response to the sociocultural need to maintain historical cities and the environmental need to reduce the global energy demand of existing buildings.

Small historical villages, and in particular those with fewer than 5.000 inhabitants, are undergoing a declining process, due to the lack of infrastructure, services, cultural attractiveness and because of the inadequate actions aimed at their valorisation. They are often underused, abandoned or neglected, thus risking being affected by severe degradation. For this reason, European and national directives strongly encourage actions targeting the revitalisation of small villages, in order to preserve their historical heritage and improve their energy efficiency. This study aims at investigating Italian examples of the revitalisation of small historical towns, showcasing what strategies they employed for the maximisation of social engagement and inclusion, reduction of the environmental impact and energy efficiency improvement. This paper will propose a methodological approach leading towards the creation of Energy Communities within small historical villages, not only addressing the need for clean energy supply and environmental impact mitigation, but also respecting and preserving the heritage value and covering the social, economic, and cultural aspects of the revitalisation.

Keywords: Small historical villages, Cultural heritage renovation, Energy Communities.

List of Abbreviations

ANCI	Italian National Association of Municipalities
CE	Circular Economy
CH	Cultural Heritage
EC(s)	Energy Community(s)

EED	Energy Efficiency Directive
EMI	Directive on common rules for the internal market for electricity
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Company
EU	European Union
NRRP	National Recovery and Resilience Plan
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SME(s)	Small and medium-sized enterprise(s)

1 Introduction

Within the European context, historical centres represent a core part of the anthropic environment, comprising the most extensive concentration of cultural heritage (CH) and historical buildings, thus representing the cultural identity of a community. As suggested since the *World Heritage Convention* in 1972, such cultural and historical heritage needs to be preserved as much as possible, on account of its potential role in enhancing societal cohesion and development, and pursuing peace and justice.

The fundamental role of small urban areas has already been widely acknowledged on account of their cultural value, historical legacy, environmental role, endogenous features, connection with landscape and potential as alternative models to cities [1]. In fact, small historical villages commonly maintain the vernacular heritage of a population, thus representing the cultural expression of a community, of its diversity and of its relation with the surrounding territory [2], which has to be protected and preserved.

Small villages are part of our past and present history, constitute our identity, retain the valuable cultural heritage and therefore deserve our most attention and care. Hence, there is a need to generate initiatives to protect the memory and heritage of former communities and residents.

In Europe, historical buildings account for over 30% of the overall building stock [3], with higher percentages in some countries, such as Italy, where architectural heritage constitutes at least 46% of the entire built environment [4].

On the other hand, such a relevant number of aged buildings significantly contributes to the national final energy consumption. Besides the high costs and emission levels, the low performance of historical buildings often results in the poor environmental quality of indoor spaces, with severe consequences on users' comfort and perception (e.g., low thermal performance, moisture-induced building pathologies, etc.).

For these reasons, the importance of operating on such heritage is twofold: the sociocultural need to preserve and maintain historical cities and their individual values, so as the environmental need to reduce the global energy demand of the existing building stock.

This study aims at investigating some Italian examples of the revitalisation of historical centres through the creation of Energy Communities (ECs), showcasing what strategies they employed for the maximisation of social engagement and inclusion, the reduction of the environmental impact and the improvement of CH energy efficiency. The most effective and replicable experiences will be presented, providing insight into the suitable strategies that could be applied to future interventions.

2 Materials and Methods

The research is based on a significant work of data collection, mainly through: (i) literature review processes, to define the state-of-the-art concerning the renovation of small historical villages with respect to current approaches; (ii) review of European and national directives; (iii) analysis of Italian examples and best practices.

At the initial stage, the analysis of documents and literature – conducted through the search on the main reliable databases (such as Scopus, Researchgate, Google Scholar, etc.) as well as on official websites of the main international organisations involved in CH and small villages (UNESCO, ICOMOS, etc.) – served the purpose of attaining a clear and univocal definition of "small historical village". In addition, the objective of this review, coupled with the analysis of existing best practices, was to identify the main issues and risks affecting small historical villages, especially in relation to their currently increasing abandonment trend, as key concepts for a better and deeper understanding of the topic.

The review of European and national directives was oriented towards the understanding of current and future opportunities, and financial instruments for the development of regeneration strategies for small historical villages. The data gathering process was also applied to the identification of the current approaches to the renovation of small historical villages, in order to determine possible research gaps, which involved: (i) the review of parameters, across several references, influencing the regeneration interventions; and (ii) the recognition of challenges and obstacles of such actions. This analysis led to the detection of a scarcity of cohesive national revitalisation strategies for small towns, as most of the approaches are still based on "individual" solutions applied at the building scale, rather than more holistic large-scale methodologies. To support the validation and description of multi-scale and community-based approaches to the revitalisation of small towns, as well as the advantages they confer to the optimisation of this regeneration process, some Italian examples were chosen as "good practices".

A search on the main databases and on the available reports and mappings of Energy Communities in Italy (such as those provided by Legambiente) was carried out to study the progress of renovation and implementation of ECs within small historical villages. The examples were selected prioritising those that met the following criteria: (i) compliance with the definition of small historical village; (ii) application of regeneration intervention at the town scale; (iii) implementation of ECs[5]; and, when possible, at least one among the following: (a) involvement of the local community; (b) adoption of compensation strategies at the town-scale; (c) capitalisation of the features and assets that are typical of a specific territory. Among the eligible examples, the most aligned with the strategies proposed in this contribution were selected, prioritising those characterised by differences and peculiarities (in relation to the abovementioned parameters that affect the regeneration actions), in order to provide evidence of the feasibility of the proposed approach in different contexts.

3 Results and Discussion

3.1 Historical Villages: Depopulation and Energy Performance-Related Risks

Small historical villages[6] are often defined as settlements that have maintained the recognisability of their structure and the continuity of their historical building fabric – where their original typological and morphological characteristics are evident – and identified by high historical-artistic, architectural or landscape value [5].

Although national definitions of "towns" differ across countries worldwide, they can generally be assumed as isolated historical urban aggregates with a demographic size limit of 5.000 inhabitants. In fact, out of the 100 countries that use the population size threshold as a defining criterion to distinguish between cities, towns and rural areas, 85 use the 5.000 threshold or a lower threshold [6]. Sometimes, instead, the "Degree of Urbanisation" is used as a selection criterion to define the character of an area based on population density, with towns being described as "semi-dense areas which have a population of at least 5.000 inhabitants in contiguous grid cells with a density of at least 300 inhabitants per km^2" [7].

For this paper's aim, we intend small historical villages as those where the urban aggregates and their surroundings, whether urban or rural, however dense, are of recognised value from the historical, artistic, scientific, social or ethnological point of view. In some cases (small or very small municipalities) these can even correspond to a number of scattered, albeit mutually related, settlements.

Small historical villages constitute fragile environments, often located in marginal areas isolated from main urban centres, due to their complex orography, their fragile economy, and high environmental risks, recently exacerbated by the effects of climate change. These features led them to progressively face abandonment or depopulation phenomena, due to the lack of infrastructure, services, cultural attractiveness and because of the inadequate actions aimed at their valorisation. These adverse circumstances determined growing socio-economic issues and technological degradation of buildings and infrastructure. In the last decade, the decline of small towns and villages assumed

[5]With the exception of the first example (Torri Superiore) which includes energy-saving and low-impact solutions but does not "formally" match this criterion. However, it was selected because of its peculiarity of being a completely abandoned village prior to the renovation interventions.

[6]The terms villages and towns will be used interchangeably here.

considerable dimensions, with consequences on the conservation and protection of a wide and important cultural heritage.

This negative trend is especially evident in Italy, which has 4,7% of the world's architectural heritage, and where small historical villages involve approximately 22% of its population [4].

Here, the social and economic transformations that occurred in the last sixty years have had great consequences on the depopulation of small urban centres, leading to more than 80% of the national population living in few larger cities, with concurrent disuse of large parts of the territory that are no longer maintained and therefore in a state of advanced abandonment. However, in Italy, 70% of Municipalities have fewer than 5.000 inhabitants, covering 55% of the overall national territory and accounting for almost 10 million residents (Fig.1). Among these, over 2.830 are at risk of disappearing, due to major collapse as a result of neglect, despoliation by local populations, ordinary natural events (e.g. rainfall, temperature fluctuations, etc.) and extraordinary events (e.g. floods, earthquakes, etc.) [8].

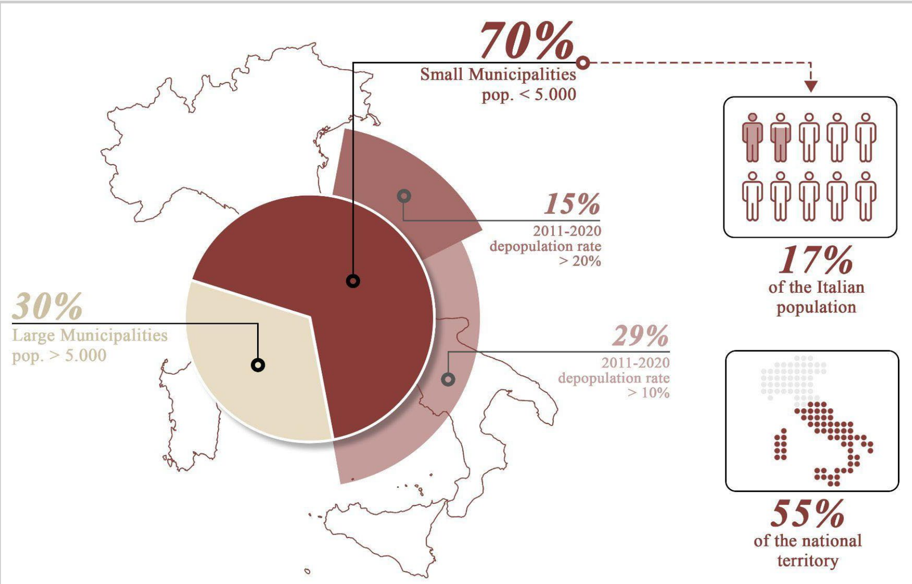

Fig. 1. Distribution of small and large Municipalities in Italy and percentage of small Municipalities undergoing a > 10% or > 20% depopulation rate (source: authors' own elaboration).

As small towns are underused, abandoned or neglected, and their tangible cultural heritage is threatened to be affected by degradation, the major risk to be faced is the permanent loss of their intangible cultural value. Intangible cultural heritage includes all expressions that communities and groups recognise as part of their cultural heritage, constantly recreated in response to their environment, their interaction with nature and their history, which provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity [9].

On the other hand, it must be considered that the share of buildings dating prior to 1945 represents an average of 26% of the whole building stock in European countries [10]. Such a relevant number of aged buildings significantly contributes to the national final energy consumption. It has been estimated that, in relation to different European countries, such value may vary between 27% and 42% of the overall energy demand [11]. In fact, historical buildings, and in particular those built before 1945, are usually low-performance by definition [12]. Besides the high costs and emission levels, the low performance of historical buildings often results in poor environmental quality of indoor spaces, with severe consequences on users' comfort and perception (e.g., low thermal performance, moisture-induced building pathologies, etc.).

However, the renovation of historical built environments is a challenging task, as often the need to maintain the aesthetic value does not allow to apply standard packages of solutions. Energy retrofit and renovation techniques for high-quality design and construction, able to preserve the cultural value of heritage buildings, have to consciously balance different requirements, and retrofitting technologies have to be weighted on their reversibility or invasiveness, considering the whole environmental impact of each solution [13].

On such occasions, renovation strategies must preconceive and evaluate the compatibility of renovation measures and establish their respectful implementation, which has reportedly proven to be feasible and consistent with energy efficiency improvement. In fact, completed projects have shown that reducing the building's energy demand by 75% may be possible for historical buildings, while preserving their heritage value [14].

3.2 European and National Directives Promoting Preservation and Revitalisation of Small Historical Villages

European and national directives are strongly encouraging actions that target the revitalisation of such villages, in order to preserve their historical heritage and improve their energy efficiency.

The European Union (EU) coordinates and supports policies, measures and investments around the preservation of cultural heritage with growing interest since the Treaty of Maastricht (1992). In 2005, the Faro Convention (Framework Convention on the Value of Cultural Heritage for Society) cast light on the socio-economic advantages of preserving cultural heritage while, in 2014, the CoE Parliamentary Assembly adopted Recommendation 2038, "Europe's endangered heritage", seeking to interlink culture, heritage and education to encourage implementation of conservation of cultural heritage and community-led urban strategies in historical towns.

The publication of the "Cultural Heritage Counts for Europe" report, in 2015, opened a door for the improvement of investments in the field, by highlighting the beneficial effects of cultural heritage. 2018 was designated as the European Year of Cultural Heritage by the European Commission, and it represented an opportunity to progress in conservation, especially with the publication of The European Framework for Action on Cultural Heritage, with the aim of setting a common direction for heritage-related activities at European level, primarily in EU policies and programmes.

In general, the European policies and documents about cultural heritage stress its importance in the three main pillars of sustainable development: 1) **economic**, as cultural heritage represents a strong asset in tourism, thus leading to a positive economic impact on job creation; 2) **social**, as cultural heritage can foster integration, inclusiveness, cohesion and participation; 3) **environmental**, as innovative and sustainable use of cultural heritage can enable the sustainable development of European landscapes and environments [15].

In fact, the preservation of historical and cultural tangible and intangible values is a prerequisite for achieving sustainable development. The adoption of the World Heritage Sustainable Development Policy (2015) reminds us of the importance of cultural heritage in the attainment of the UN Sustainable Development Goals, mainly referring to Target 11 "Make cities and human settlements inclusive, safe, resilient and sustainable", to enhance inclusive and sustainable urbanisation and safeguarding cultural and natural heritage.

On the other hand, in many European countries, a sizable proportion of the existing building stock is represented by historical buildings, many of which are inadequately performing in terms of energy consumption and indoor environmental quality. For this reason, and because such heritage can only be preserved if maintained as living space, the interest in the preservation of historical buildings has been shifting towards the identification of compatible energy retrofit solutions, allowing to improve users' comfort, lower energy costs and minimise the environmental impact, while maintaining the aesthetic and cultural values [14]. The latest trends have shown that even historical buildings shall aim to be aligned with the Energy Efficiency Directive (EED) and Energy Performance of Buildings Directive (EPBD) to meet the EU's climate objectives, as well as national building renovation plans [16].

In fact, after the Paris Agreement (2015) set the target of arresting global warming to 1.5° and the European Green Deal and 2030 Climate Target Plan (2019) introduced new measures to achieve carbon neutrality by 2050, in 2020, as a flagship of the Green Deal, the European Renovation Wave directly addressed this need, proposing to double annual energy renovation rates throughout the next 10 years and to encourage deep renovations. In the EPDB novel version revised by the EU Commission in 2021, it was also proposed that public administrations should be required to renovate at least 3% of their total owned building floor area each year.

Given the extent of the renovation requirements, to meet the challenges posed by sustainable development, rural areas offer many opportunities, especially in terms of resilience against climate change, provision of alternatives to fossil fuels and development of Circular Economy (CE) principles. For these reasons, European policies also encourage the development of "smart villages" within the existing ones, defined as those able to use digital technologies and innovations to enhance standards of public services and ensure better use of resources. Their role in providing a balanced territorial distribution of the population – avoiding overpopulation of cities – is crucial, while their quality of life is increasingly valued as is the contribution that the cultural heritage of rural areas makes to sustainable tourism [17].

While the EU provides economic resources for the preservation and rehabilitation of cultural heritage in small towns through several funding programmes (e.g. EU Cohesion Policy, Regional development investments, European Agricultural Fund for Rural Development, etc.), at the national level countries are encouraged to enhance their peculiar historical assets.

In this respect, in Italy, the National Recovery and Resilience Plan (NRRP) paves the way for new intervention lines, directed towards the revitalisation of the relevant number of historical towns, in particular of those with a population of fewer than 5.000 inhabitants. Line A (420 million euros) aims at supporting "pilot projects for the cultural, social and economic regeneration of villages undergoing abandonment or neglect, through the implementation of a limited number of exemplary actions", one for each of the 21 Italian Regions. Conversely, Line B (580 million euros) promotes the "regeneration, valorisation and management of the historical, artistic, cultural and traditional heritage of small towns, both for its protection and for the need of social and economic revitalisation, creation of job opportunities and combating depopulation".

These investments are to be considered as a follow-up to the previously issued Law 158/2017, which aimed at introducing measures to support residents and productive activities within small Municipalities that display at least one of the following parameters[7]: hydrogeological instability; economic hardship; depopulation trend; demographic (due to age, unemployment) and urban disadvantages (rural area); lack of social services; communication struggles (due to lacking infrastructure or distance); low population density; presence of Municipality clustering or previous merging; presence of protected natural areas.

These financial instruments alone are not enough: to achieve the desirable paradigm shift towards small towns that are more attractive, self-reliant and interconnected, on one hand, and more resilient and energy efficient, on the other, there is a strong need for a cohesive national revitalisation strategy, aimed at identifying the specific assets and resources of each area, leveraging them as *drivers* for the reorganisation and development of these "territorial archipelagos" [18].

3.3 Current and Proposed Approaches to the Renovation of Small Historical Villages

Within the European context, the identification of strategies for the revitalisation of small historical villages is complicated due to, among other reasons, the diversification of features that, albeit recurring, are noticeably variable, thus motivating that the application of certain solutions is not directly replicable or transferable to other contexts. The following section briefly introduces an overview of the main features leading to possible categorisations of small historical villages.

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[7] The Italian Government published the list of the 5.518 eligible Municipalities, and relative parameters, in September 2021: https://www.gazzettaufficiale.it/do/atto/serie_generale/caricaPdf?cdimg=21A0536500100010110001&dgu=2021-09-14&art.dataPubblicazioneGazzetta=2021-09-14&art.codiceRedazionale=21A05365&art.num=1&art.tiposerie=SG.

3.4 Main Categories of Parameters Influencing the Renovation of Historical Small Villages

As a general introduction, small villages can be categorised according to several parameters (Fig.2). Some attain the site conditions of the small town's location, others concern the historical period, the architectural background (typological and morphological features) and the construction systems, some others the population living in the village and their primary sources of revenue.

Among those parameters belonging to the first category, some significant ones could be: 1) **geo-cluster**, based on the usual definition of European climatic zones (Köppen climate classification); 2) **elevation**, which typically refers to their height above sea level and the geomorphological typology of the area (mountain, hill, plain or coastal villages)[8]; 3) **accessibility**, which relates to distance from main urban centres, easy and convenient access to public and private transport, but can be also extended to digital and communication service availability (i.e. access to internet).

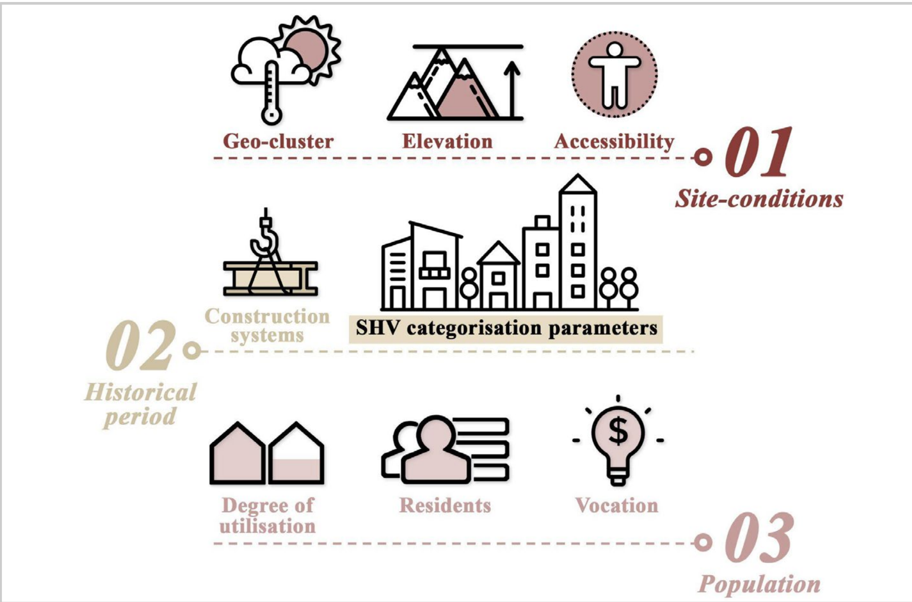

Fig. 2. Proposed main categorisation parameters for small historical villages (source: authors' own elaboration).

Some of the parameters that are part of the second category – referring to the villages' historical, architectural, urban and construction background – are strictly related to those regarding their geographical location: the **construction systems** used within

[8]This categorisation has been used in the "Atlas of Small Municipalities", published in 2012 by the Italian National Association of Municipalities" (ANCI).

historical villages differ significantly according to the history and traditions of a place, which are undoubtedly influenced by climate, available materials and local resources.

Within the third category of parameters, there are some that are worth mentioning: 1) the **degree of utilisation** defines whether the village is fully abandoned, partially abandoned, mostly inhabited, or its residents may have relocated to a new urban aggregate[9]; similar categorisations refer to this parameters as "exodus", "steady" and "counter-exodus", indicating an increasing, stable or decreasing depopulation rate[10]; 2) all that concerns the **residents** influences potential interventions for the revitalisation of small villages (in terms of population age, ethnicity, habits, etc.); 3) primary **vocation** of the village, which is strictly connected to the main employment sector and the activities the residents engage with. Such vocations have been grouped by previous research studies[11] and can be summarised as follows: tourism and real estate; production; socio-cultural; artistic; experimental.

As this introduction shows, the number and the diversification of small historical villages do not allow for general solutions to their revitalisation. Some are still endowed with a certain degree of vitality and dynamism, which might facilitate their regeneration, while others are afflicted by the condition of marginality, which prevents them from possibly being revitalised without external triggers [19]. Other aspects to be considered as potential obstacles, especially regarding the need to improve the energy efficiency and environmental indoor quality within historical buildings, are the need to preserve the aesthetic and architectural value of the cultural heritage (especially for listed buildings) and landscape, as well as the typological and stylistic identity, often in close relation with the buildings' construction techniques derived from a specific historical period. Other recurring challenges are the technical/legal restrictions, the aged infrastructures and non-flexible systems, the need for substantial investments, and other issues concerning ownership and usage patterns, also considering the potential digital divide and energy poverty phenomena.

However, although the requirements differ based on several conditions – compelling to assess them on a case-by-case basis, in relation to preservation requirements, structural and material construction systems, and site-specific climatic conditions – by categorising recurring historical elements and features defining historical built environments, and crossing this information with the site-specific characters of the existing, solutions that have already been implemented can provide a good basis for further planning, by identification of suitable approaches [20].

For all these reasons, the current practice of renovation in such contexts frequently favours interventions on individual buildings, with the actors involved in this process (e.g. Municipalities, owners, private investors, etc.) generally intercepting

[9]This definition has been introduced by a research study conducted since 2006 at the Department of Architecture of Politecnico di Milano, coordinated by Prof. G. Postiglione, "Geografie dell'abbandono".
[10]This categorisation, as well as the following one (residents) can be retrieved in the previously mentioned "Atlas of Small Municipalities".
[11]"L'Italia dei borghi. Abbandono e nuove prospettive" by D. Benedini (2020) and "Borghi-reloaded" by G. Postiglione and M. Menconi (2018).

opportunities whenever possible, thus generating incoherent and inconsistent episodes rather than efficient and farsighted strategies.

However, it is recognised that the methodologies based on individual buildings or stand-alone solutions are not sufficient to overmatch the transition barriers because, among other issues, they do not consider the whole urban system and the synergies that can be created at a community level [21]; acting instead at the "urban" scale, considering building aggregates and related connections and infrastructures, allows to increase those synergies, speeding up renovation, rehabilitation, and repurposing processes, triggering on compensation strategies among the different involved scales.

As a consequence of this, large-scale renovation actions are crucial to oppose depopulation and gentrification in marginal areas, while retaining the unique identity of small historical villages. Hence, there is an urgent need for the development of multi-scale community-based strategies for wide compatible adaptive reuse, restoration and energy efficiency refurbishment to: preserve and maintain the cultural heritage within small historical villages; valorise their historical identity; improve quality of life and comfort for end-users; reduce the environmental impact towards carbon neutrality and lower emissions; improve resilience of rural areas; and enhance inclusiveness and accessibility of historical sites.

3.5 Multi-Scale and Community-Based Approaches to the Regeneration of Small Historical Villages in Italy through the Creation of Energy Communities and Examples

As previously mentioned, the Italian case is representative of the more generalised condition of marginalisation and neglect of small villages, especially when located in rural areas, although they represent a highly valued heritage and, quoting Daniel Libeskind, they "enclose the DNA of humanity" (2016). There are several structural motivations for these "settlement defects", such as demographic weakness (e.g falling birth rates, growing elderly population, etc.), depletion of productivity potential, poor attractiveness and limited appeal to new residents or small enterprises. It was estimated that at least 3.145 small Municipalities, accounting for the 38,8% of the total number, suffer from this condition [22]. In addition, such territories often lack the capacity to promote their tourist identity, albeit their potential, respecting their own vocations and traditions, harnessing environmental, economic and cultural assets.

To oppose this negative trend, several past and recent initiatives were launched by individuals and communities in order to revitalise small historical villages by reanimating their attractiveness.

Most of these initiatives, according to their own objectives and inclinations, advanced and enforced synergies and networking systems at local level, or created collaborative and widely-accepted actions, in order to achieve enhanced liveability, productivity, or tourism, and eventually improved well-being for residents and visitors.

In this respect, it is interesting to note that, in recent years, an increasing number of experiences were activated in order to create Energy Communities within small towns. These are new models arisen from the need to evaluate conservation and adaptation measures from the perspective of Circular Economy but also to foster the decarbonization process in historical urban areas, using innovative approaches of energy management, advanced materials, and applying Renewable Energy Sources (RES) [23]. ECs are defined as legal entities involving citizens' participation as *prosumers* in the future energy system that should integrate social justice principles [24]. They can be organised in various collective forms for the decentralisation and the local operation of renewable energy [25].

Among the strategies towards decarbonisation by 2050 foreseen by the "Clean Energy for All Europeans Package" (2019), the most important directives are: the Renewable Energy Directive 2018/2001 (better known as RED II); the Directive on common rules for the internal market for electricity 2019/944 (so-called EMI Directive).

The main purpose of the RED II Directive is to increase the share of energy produced from RES in the EU and to increase citizen's involvement in the installation of renewables. In addition, this directive aims at addressing the energy poverty issue by fostering inclusiveness of vulnerable customers in the energy transition pathway. Instead, the EMI Directive shall adapt the EU electricity market to the most recent technological and structural changes, dealing with the production and exchange of electricity – whether from renewable or traditional sources – and the methods of participation in energy services. Although collective self-consumption of energy has already been recognised in some EU national legal frameworks or in pilot projects, this directive offered the opportunity to formally recognise it in legislation at EU level. RED II and EMI Directives provide for the first time an enabling EU legal framework for collective citizen participation in the energy system [26]. This represented a turning point for Energy Communities, as their recognition endorses their creation.

In Italy, the implementation of the abovementioned directives began in 2020, with "Decreto Milleproroghe", introducing for the first time the definitions of "jointly-acting renewable self-consumers" and "Renewable Energy Communities". This was followed by the publication of the ARERA Resolution 318/2020 (August 2020), the MiSE Decree (September 2020) and the technical rules by GSE (December 2020), leading to a pilot phase for the creation of ECs.

Along this period, a rising interest sparked around this legal form of cooperation among citizens that, coupled with the empowerment of individuals within the energy system, enables customers to take a more active role. In fact, ECs stand out as significant facilitators for the participation of individuals and communities in the energy system, promoting self-consumption and contributing to the social acceptance of renewable energy implementation initiatives, allowing for several additional benefits.

Despite the most recent evolutions, it has to be stated that community-based approaches for the sustainable regeneration of small towns had been experienced long before ECs were defined by statute.

This is the case of **Torri Superiore**, a small mediaeval town located at a distance of approximately 10 kms from Ventimiglia, in Liguria. As reported by Briatore [27], before its revitalisation, Torri Superiore was completely abandoned: its depopulation began as early as the 19th century, due to the lack of employment opportunities and the geographical location, which caused the town to witness several changes in the border between Italy and France for over a century. The small village's buildings were divided into several properties, as it often happens in underused areas due to inheritance processes and lack of functional reorganisation. The interventions began in the early 1990s, when the members of the "Cultural Association of Torri Superiore", founded in the '80s, started purchasing part of the properties, up to the acquisition of approximately 90% of the village. The aim of the association was, on one hand, the restoration of the buildings and the recovery of the cultural, architectural and landscape heritage and open spaces: on the other, the development of a different societal model, based on collective and individual economic activities that provide for the inhabitants, enabling them to afford living in the small town [27]. Under the architectural point of view, the recovery project, often prosecuted by the local population itself, preserved the original features of the urban and building aggregates, while integrating them with modern technologies for comfortable living and for low environmental impact, encouraging the use of natural materials and energy-saving technologies. As for the latter, hot water is produced by solar panels; heating systems consist of low-temperature radiant surfaces (with air temperature does not exceed 18°C) ensuring thermal comfort and energy savings; electricity is supplied by a private company and entirely produced from RES; wastewater is collected and reused within composting systems.

Overall, not only did this ambitious project regenerate the historical heritage of the town, but it recreated a community within it that would share common values and benefits, in the form of "ecovillage", a human-centric settlement striving to pursue sustainable living models in harmony with the environment.

In more recent years, thanks to the implementation of ECs within legal national frameworks, some of these initiatives have resulted in the formal organisation of Energy Communities, some of which have started to advance even within small historical towns. An example of this can be encountered in the **Municipality of Ferla**, located in Sicily and accounting for about 2.300 inhabitants. The origins of this town date back to the mediaeval times, with traces from that period remaining in the urban structure and narrow street recall the architectural traits of old villages (Fig.3).

However, major parts of the town were reconstructed after a destructive earthquake occurred in the 17^{th} century. Here, under the guidance of the illuminated administration, an Association was created with the aim of engaging citizens, SMEs or other stakeholders seated on the municipal territory, both as consumers of clean energy produced by the public photovoltaic installations or as prosumers, placing their renewable energy production systems at everyone's disposal. The Municipality, within the pilot project devised by MULTIPLY (H2020) and in collaboration with University of Catania, installed several solar power systems – for a total capacity of 185 kW – on public properties, some of which within the historical centre, with the endorsement of the bodies responsible for heritage conservation. Thanks to these units, sufficient electrical energy is produced to meet over 40% of the energy demand from public facilities, thus leading to considerable savings for the public administration, as well as receiving significant economic contributions for clean energy production. Environment wise, this means that approximately 292 tonnes/year of CO_2 are prevented from being released into the atmosphere [28].

Fig. 3. Historical centre of Ferla, Sicily. Clemensfranz, CC BY-SA 3.0, via Wikimedia Commons. http://creativecommons.org/licenses/by-sa/3.0/.

Together with the integration of RES, the Municipality of Ferla promotes measures to improve the waste reduction rate and the distribution of free drinking water. These actions are aimed towards the ecological transition, with the fulfilment of CE and sustainable lifestyles, but also and foremost favourably impact the quality of life and well-being for residents within the village, social cohesion, innovation and fair employment.

These side benefits do not come as a surprise: as a matter of fact, the primary purpose of Energy Communities is to provide environmental, economic and social community advantages for shareholders and members, as well as for the local areas where they operate, with the additional contributing factor given by financial profits [29].

In fact, there are several factors, besides all previously mentioned diversities and variabilities among small towns, that represent the common ground for the activation of renovation and energy improvement strategies at the village or district scale, rather than at the building scale. The reported experiences, as well as the motivations and the rationale behind Energy Communities, seize and build upon these opportunities.

More specifically, the advantages to be leveraged when operating on the village altogether are highlighted below.

- Possibility to **engage with the community**. In recent years, some initiatives, striving to transform the town's condition of marginality into an opportunity to revitalise a deep cultural and territorial identity, have shown that spontaneous associations of people are key to develop the re-appropriation, acceptance and valorisation of values and places[12] [30]. The value of engaging with the

[12]In Italy, some initiatives are promoted by associations such as "I Borghi più Belli d'Italia", "Bandiere Arancioni", "Touring Club", some others result from local processes activated by residents that have built a collaboration.

community is given by the desire of local populations to carry out actions – driven by innovation and creativity – that are not only "productive" or "promotional", but genuinely aimed at safeguarding the memory and heritage of their past that would otherwise risk being lost. This generates opportunities for communities to be empowered and thrive. In this sense, the community can be intended as either residents or users of inhabited villages, or potential future users and stakeholders of neglected or abandoned towns.

- Possibility to operate both at the building and urban scale, adopting **compensation strategies** aimed at achieving high quality standards of the renovated village – especially in terms of resilience, sustainability and energy efficiency – where restrictions and constraints (e.g. considerable number of listed buildings, density of building blocks, etc.) do not allow to foresee the expected results just through limited actions on individual buildings. This, instead, can be accomplished by additional interventions on connective spaces (e.g. vegetation, ground surface materials, etc.) or even on the surrounding areas of the historical settlement (e.g. installation of photovoltaic panels or use of other renewable energy sources).
- Possibility to **capitalise the assets** provided by each specific site: social assets (e.g diversities within the communities, habits, etc.); cultural assets (tangible and intangible cultural heritage); economic assets (e.g. agricultural/ tourist/industrial activities, local products or goods, etc.); energy assets (renewable energy sources to be used); natural assets (e.g. unique landscape, protected natural areas, etc.).

In order to maximise these favourable aspects, ECs can represent a starting point for the implementation of novel collaborative business models exploiting the cultural/historical assets and resources of a place, while introducing technologies to improve energy performance, conforming to European socio-ecological and climate objectives. In this respect, the opportunities offered by RES usage in historical towns are substantial for the reduction of energy demand and, accordingly, towards achieving net zero energy buildings, especially if solar panels and collectors wisely integrated as to not interfere from an aesthetic perspective, and their installation is reversible [14].

Recent experiences demonstrate the potential of this approach, although the above discussed large-scale operational conditions (i.e. community engagement, compensation strategies and capitalisation of local assets) often appear independently rather than framed in combination for their mutual optimisation.

Ventotene, a small island in the Tyrrhenian Sea, with 800 inhabitants, belonging to the Province of Latina, in Lazio, embarked on one of these worthwhile ventures (Fig.4). In October 2021, a small Energy Community was inaugurated, supported by the Municipality, La Sapienza University and Regional funds allocated by the "Vitamina G" project call [31]. In formulating the project, the public and private stakeholders were involved, along and foremost with citizens, conducting a *participatory process* aimed at fostering a shared sense of belonging for the community as a whole; these experimentations were integrated with activities aimed at raising awareness and providing education on environmental-responsible behaviours.

Fig. 4. Ventotene, small island in the Tyrrhenian Sea. IslandVita, CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0, via Wikimedia Commons.

In **Biccari** (Province of Foggia, Puglia), registering approximately 2.700 residents, the Municipality – supported by the Region and the EU – has operated several interventions for the valorisation of the natural and built environment. In collaboration with the "ènostra" energy cooperative, the administration intends to finalise the constitution of a Renewable Energy Community, with a threefold objective: to further develop its long running activities to improve landscape quality and environmental sustainability, through which Biccari has already achieved promising results in tourism attractiveness; to address energy poverty issues by installing photovoltaic panels on public housing; to maximise self-consumption on all municipal properties through the acceleration on the generation of renewable energy from RES [32]. One interesting fact is that the municipality has devised the delocalisation of on-site exchange systems, positioning car-parking photovoltaic shelters outside the town centre, adopting this *compensation strategy* in order to overcome the barriers given by the installation of plants within historical buildings.

A different model is pursued within the small Renewable Energy Community associating citizens in the **Municipality of Gallese** – a small town accounting almost 3.000 inhabitants in the province of Viterbo (Lazio) – that owes its setup to the initiative of an existing "Bio-district" association and the EU funded project REDREAM (H2020). The ambition is to acquire a photovoltaic solar power plant, currently estimated at a total power of 200 kW, to be financed by an ESCO (Energy Service Company). This will support and enhance the agricultural enterprises operating on the territory of Gallese, which represent the local economic drive force, as well as the main *cultural and landscape asset*. Over the years, the "Bio-district" has committed to implementing strategies and objectives in the field of recycling waste, biodiversity protection and management of energy resources, thanks to the local farming businesses. All these activities, intertwined within the new EC, will expectedly stimulate the further revitalisation and regeneration of the natural and built environment.

What such experiences have in common is the capacity of being pervasive in the internalisation and embracement of local resources, whether physical, cultural, or even represented by the community itself and its sense of belonging, allowing them to become the catalyst for economic and social development. The key to success of these projects was the capacity of capitalising the main local – internal or territorial – assets, confronting the challenge of turning them into their own peculiar vocations, thus producing added value for the community.

Each of the proposed examples offered appropriate reflections and evidence on the effectiveness and replicability of each initiative, as well as on the possibility to combine different strategies and solutions for the maximisation of their beneficial effects, according to three different focus areas that were analysed in relation to the objectives of this contribution. These main lines are:

- **community engagement**: the relevance of participatory approaches and community engagement emerged from several experiences; the definition of community is extended to both local residents, for inhabited villages, and future stakeholders and end-users, for depopulated ones;
- **environmental impact**: it is intended both as the compatibility of building reuse and interventions in respect of the natural/urban/historical context of the village, as well as the effects produced and observed by the pursued actions on the wider environment, towards decarbonisation and energy efficiency;
- **business venture**: there were several types of enterprise initiative, either funded by private investors, public administrations, from a joint collaboration between private and public actors or from bottom-up approaches.

In this respect, these experiences can be interpreted as an interesting testing ground for the application of cooperative actions based on the "T" elements that can build attractiveness and competitiveness: technology, i.e. the capacity to create innovative products and services; talents, i.e. the intrinsic tangible and, most importantly, the intangible components (e.g. knowledge, values, etc.) of a territory; tolerance, i.e. the capacity to accommodate and create a multi-ethnic and highly socially differentiated society [33].

4 Conclusions

When looking at future renovation scenarios, it must be considered that the utmost importance of preserving cultural and historical sites requires them to be prevented from abandonment and neglect, thus maintained as active and lively places. In order to do so with small historical villages, while protecting their legacy as bearers of past collective memories and values, it is necessary to overcome the traditional approach, aimed at restoring individual buildings, rather operating at different scales – territorial, urban, architectural – by performing a broader analysis, investigating their surrounding territory, focusing on their grids, networks, resources and energy potential. This allows to provide a multi-scale, human-centric and community-based methodological format to capitalise the available resources of targeted sites, aiming at benefiting from the adoption of participatory processes and optimal strategies for the appreciation of the main assets and vocations. Furthermore, this approach contributes to calibrating effective and minimally invasive interventions on the heritage built environment, thanks to the identification of compatible compensation strategies as a synthesis between energy efficiency requirements – deriving from the assessment of performance needs – and conservation priorities for the enhancement and protection of the original, architectural and constructive features.

Thanks to these factors, the valorisation of small towns is a vast field upon which a new idea of collaborative conservation and regeneration can be based, producing added value, attractiveness, growth and rebirth in contexts that are undergoing a depopulation process.

After the implementation of the latest EU and national directives legally recognising and defining certain types of community energy initiatives as Energy Communities, it appears that such collective, open and democratic entities represent an effective strategy to change the organisational and power structures that sustain small historical villages, while maintaining the possibility of heterogeneous organisational models and legal forms [26].

The proposed multi-scale integrated approach, going beyond the traditional building-based vision, conveys a more extensive outlook, allowing to devise and enact more cohesive strategies between conservation and regeneration, maintenance of cultural value and decarbonisation. In this sector, ECs have shown great potential, both in the renovation and improvement of energy efficiency, and in enhancing social cohesion, citizens' well-being, employment opportunities, even though so far they have not yet been extensively implemented within historical environments.

This contribution has strived to demonstrate that, if the benefits of ECs are coupled on one hand with wide citizens' acceptance – obtained through participatory and engagement procedures, improved social, economic and well-being conditions, and enriched collective perception – and, on the other hand, with compatible and respectful technologies for building renovation, as well as combined with compensation strategies at urban/territorial scale, it will be possible to successfully respond through on-site solutions to the key challenges presented by the urgent need for the transition of historical low-performing protected historical contexts towards climate neutrality.

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Delphi: A social survey (2022) and some proposals for the sustainable development of the area

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Abstract. The present paper addresses the issue of sustainable development of the Delphi area under the scope of Environmental Design. Delphi is a historic place with multiple points of interest due to its natural beauty, archaeological importance and its traditional character. The paper focuses upon the renovation and re-creation of a sustainable settlement, where all elements that concern the built environment and the urban area of Delphi, integrate morphologically as a whole. The proposal includes the traditional buildings' restoration and the environmental and aesthetic upgrading of the buildings, the public open spaces and their partial elements. The project's success depends on each place's comparative advantage and on the promotion and protection of both the natural environment and the cultural heritage.

Keywords: sustainable development, urban built environment, Delphi, environmental upgrading

1 Introduction

Approaching Delphi as an area of study, we find that few places in the world can simultaneously arouse so many interests. And this is because Delphi can be approached as follows: 1) as an extremely beautiful and sensitive natural environment, 2) as a sacred place for the Greeks from the mythical times with well-preserved antiquities, which show even today why they were considered as the center of the world and 3) as a small modern town based mainly on tourism and less on agriculture and livestock.

The present study refers mainly to the contemporary built environment, and not to the Antiquities area, which is a completely other subject.

1.1 A few things about the past, the present situation, the challenge, and the town

During the 19th century, French archaeologists considered that the main part of the antiquities were located under the buildings of the village of Kastri. So at the beginning of the 20th century the village was demolished and rebuilt entirely outside the outline of the antiquities, and thus the antiquities were revealed and at the same time the new settlement of Delphi town was created. When the antiquities resulted in attracting visitors, Delphi dedicated itself to providing services to the antiquities and visitors. Restoration of antiquities, a large museum, new roads in the area, many hotels and the European Cultural Center were created.

During the last 50 years, Delphi have developed economically. People from all over the world visit the area (which is estimated to be second in visits after the Acropolis of Athens) following the ironic and absurd observation: what is good for people at the same time is bad for the environment! The increase in the concentration of local people and visitors in a limited space (narrow streets, narrow sidewalks, lack of parking spaces) combined with the amazing natural environment and the ancient holy place, call for more services, more built environment, more movements and more pollution at all levels (we hardly managed to prevent an Alumina Factory in the area, 1987) and on the other hand, the antiquities, require a peaceful and quiet surrounding.

Since today's Delphi seem to be somehow neglected, we aim to achieve sustainability for the specific area with the maximum possible respect for the antiquities, the environment and the needs of the people. Many studies and proposals for the area of Delphi have been submitted during the recent decades which are either too protective for the antiquities and therefore rejected by the inhabitants and local authorities, or aimed at the economic "development" of the area and of course have been rejected by Archaeologists, and the relevant Ministries.

Consequently, it is considered necessary to approach the area of Delphi from the perspective of Environmental Design that takes into account the most possible parameters and the data that exist, aiming to propose necessary activities aimed at the sustainable development of the specific area, resulting in specific action proposals for the authorities.

The steep slopes of the terrain have imposed the town morphology of Delphi. The orientation of the blocks is mainly southwest, with the exception of some small South oriented neighborhoods. This orientation provides an excellent view of the Pleistos valley. Also, the southwest orientation is ideal regarding the sunlight, the daylight and the heat gains.

Despite the monumental sights and natural beauty, the existing buildings of the contemporary town seem to be below the expectations of Delphi; rather because the village has been built in a rush. One of the aims of the present study is the investigation of the design problems and the proposal of rehabilitation solutions. The revitalization of the area can take place on three levels; the upgrading of buildings, the recreation of public spaces and the encouragement of social activities.

1.2 Some of the problems (the present situation)

Although Delphi is a small village of 1500 inhabitants, one of the most important problems is the lack of outdoor public spaces. The total area surface of the town is about 190 acres. Only 13% are used as open spaces and 20% are roads, and there is an uneven distribution of open spaces. As a result, a lack of green spaces, playgrounds and parks is observed.

The traffic jams are an important subject that creates problems, especially during summer period. The increased number of visitors has as a result a high number of vehicles in the central part of the settlement and in front of the museum. As a consequence, a degradation of the environmental and aesthetic quality is observed. The average number of visitors, in the summer period, is estimated at 10000 persons per day. This number can reach 25000 persons per day at pick season. So, the carrying capacities of the roads network and of the parking facilities in the town are far exceeded.

At the entrance of the museum, near the archaeological site and other interesting points (Castalia Spring, Temple Pronaia etc.) the buses and vehicles are loading/uploading tourists and passengers. The parking area is of insufficient capacity for the daily number of visitors. In addition, the parking of vehicles and the large number of pedestrians, affect the operation of the highway. Therefore, congestion, noise, exhausts pollution, great risk of accidents is observed and they certainly create a serious problem to the area.

The National roadway crosses the town of Delphi. The two main local traffic roads of the town are the collector lanes of all vehicles. Also, the national roadway passes through these two roads. These roads are one-way direction and cross the other driveways and the pedestrian areas. As a result, heavy traffic and lack of parking characterize the two main streets of Delphi.

Because of this plan, the risk of accidents is increased. The majority of restaurants, souvenir shops, social and commercial activities are at these roads. An important number of inhabitants, pedestrians and tourists are crossing these roads.

The central square is one of the most important areas for the local society. It is regarded as the main area for local activities and entertainment events.

The layout of Delphi is characterized by only one square with limited uses. The position, the distance of the commercial center, the design, the access, the lack of shadowing and urban equipment, are some of the factors that cause the limited use. It seems to be situated rather outside the central activities of the city.

Lack of the necessary rest areas, urban equipment and of information centers cause difficulties to the visitors. Also, there is an absence of information signs to mark the important buildings and locations.

2 Methodology

The present study has been carried out by in situ investigation and observation of local morphology, activities, town geometry and functionality of structures. Also, a number of questionnaires were filled in by the residents and visitors. The aim of these procedures is to identify the problems regarding town planning and design and to suggest design proposals for a sustainable development.

We firmly believe that the places of attraction for foreign visitors are - or should be - the focus of particular research as well as particularly careful "development".

It is underlined here, that this study does not propose anything for the area of the antiquities, considering this as another, particular subject.

The survey results

A social survey with questionnaires took place during the summer of 2022: an updated social research on the environmental representations in the area of Delphi, of the public's environmental attitudes and perceptions of this particular charged area. 218 people participated in the survey: 98 residents, 64 foreign visitors, 56 Greek visitors.

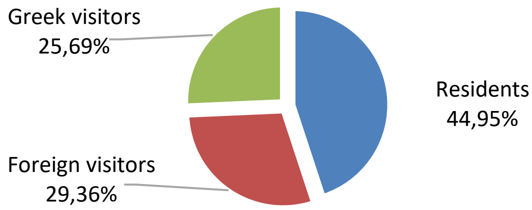

Fig. 1. Participants

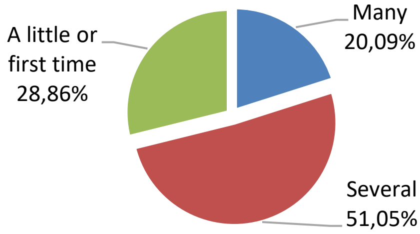

Fig. 2. Visitors. How often do you visit Delphi?

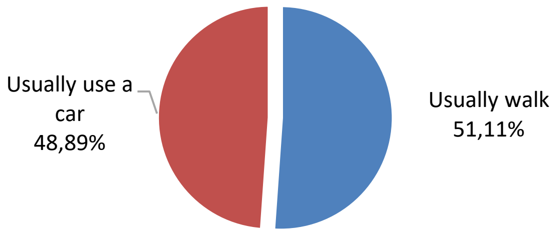

Fig. 3. Modes of transportation

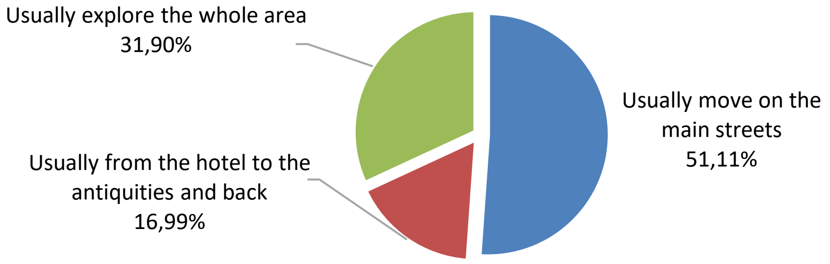

Fig. 4. Common routes in Delphi

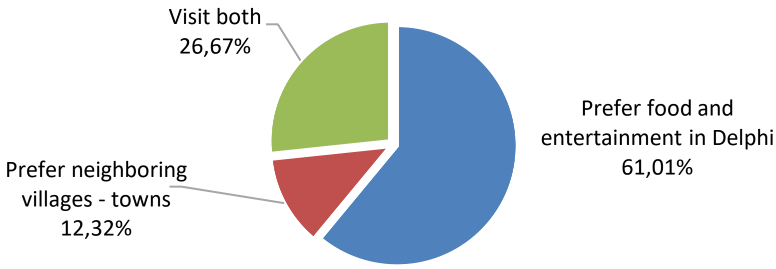

Fig. 5. Common areas for entertainment

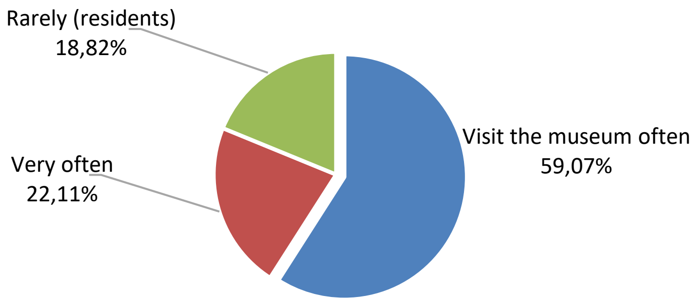

Fig. 6. Frequency of visiting the antiquities and the museum

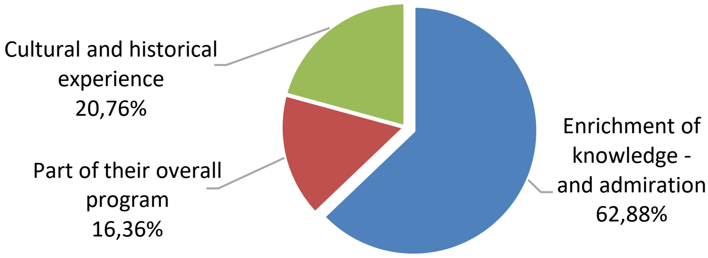

Fig. 7. Reason for visiting the antiquities

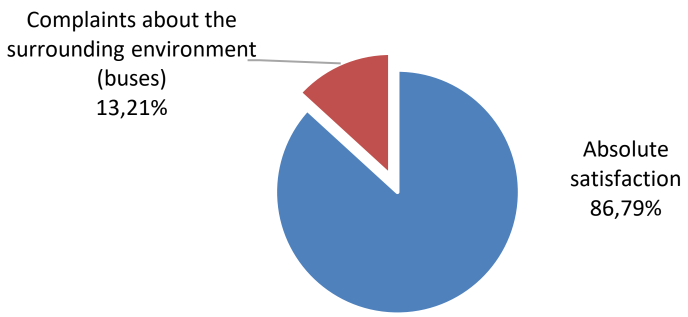

Fig. 8. Satisfaction from visiting an ancient museum

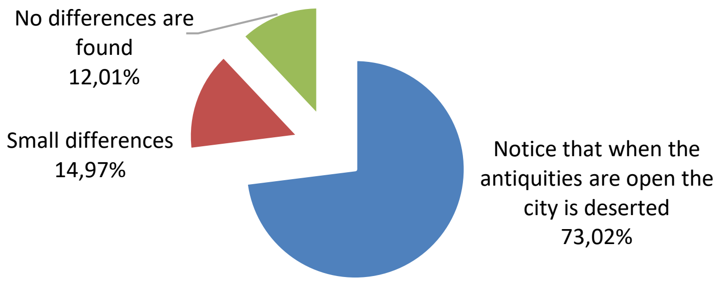

Fig. 9. Effect of antiquities on the life of the city

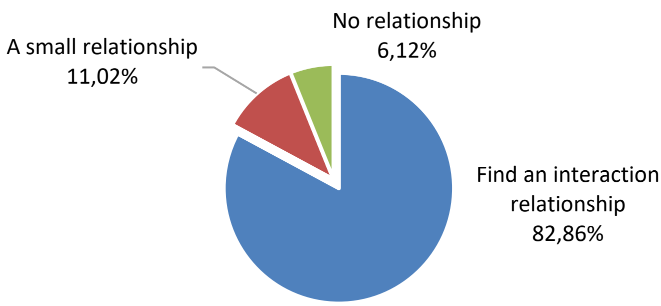

Fig. 10. Relationship between city and antiquities

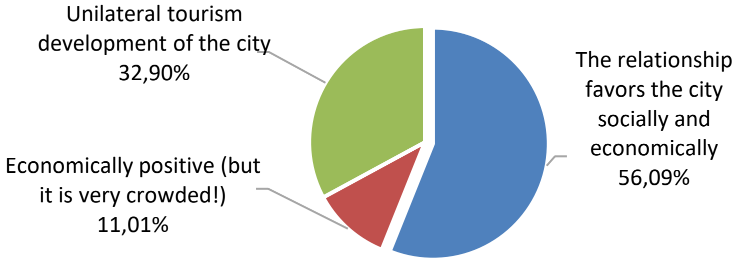

Fig. 11. Coexistence in favor of the city

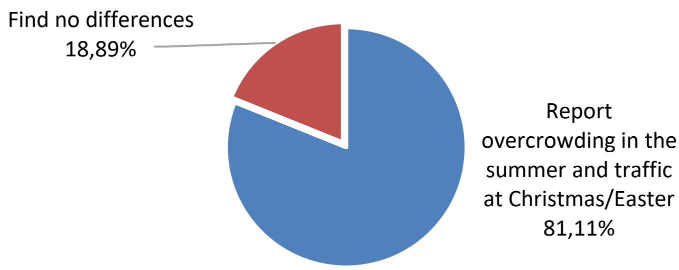

Fig. 12. Seasonal differences (visitors)

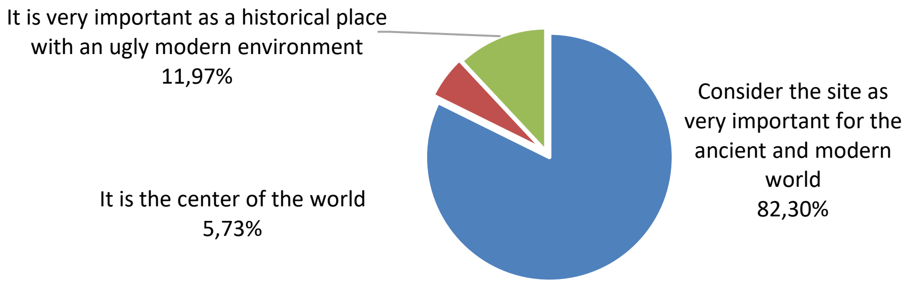

Fig. 13. What does Delphi mean to you?

3 Findings and Proposal

It is concluded that many visitors have come several times to Delphi. They combine cultural visit to the historical place with relaxation time for a coffee or a lunch in the central part of the town. They usually spend no more time in the town. So, an aesthetic development of the central road and the settlement is necessary. Also, the sustainable design of the local facilities and partial re-designing of the settlement could help to a holistic upgrading of Delphi. The configuration of the settlement and especially of the open spaces could create new environmental friendly rest areas.

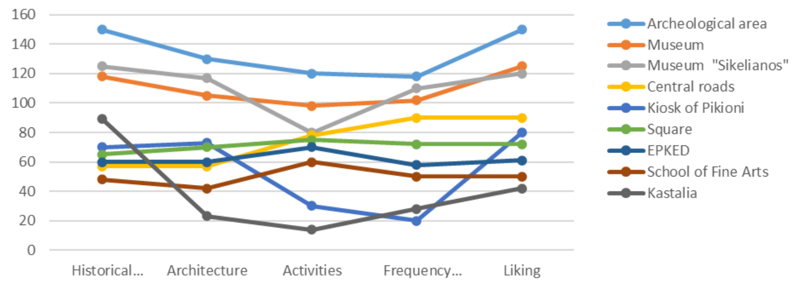

Fig. 14. Important places. According to the onsite investigation and the participants responses, the opinion of residents and visitors about the main visited areas, can been seen in this figure. ASSA (Applied Socio-Semiotic Analysis) Diagram according to Kosmopoulos (1991).

The important areas have been evaluated regarding the historical significance, the architecture, the activities, the frequency of use and the liking. The results of ASSA diagram can be obviously very useful at least to highlight the places mentioned, and the planning of visitors' new paths.

The aim of the paths proposed is to direct the visitors around the majority of the important places and to the town.

Proposals

In this part, the main proposals that have been submitted to the municipality of Delphi with the aim of the sustainability of the area are briefly presented.

It is emphasized here that Participatory Planning was implemented for the first time in Greece in the period 1983-1986, when one of the authors- as a consultant of the Municipality of Delphi-had gathered all the interested residents every Sunday morning at a central cafe, with a large map of the area stuck on the wall, to discuss the problems of the extension of the Delphi city plan, and to hear opinions about how they are affected by the possible proposals, and try to give solutions.

The final text and plans have been submitted to the Municipality of Delphi and the Ministry of the Interior (1986).

In order to revitalize Delphi, and to provide some of the respect that the place needs, we propose the following:

a. The National Road through the antiquities road separating them into two parts, and also through the narrow streets of the town. The creation of a by-pass of Delphi and the antiquities in order not to isolate and destroy completely Delphi, providing also easy access to the antiquities and the town.
b. Actions for the re-opening of Kastalia (spring and rest-area) and also re-opening of the Gymnasium and the Stadium among antiquities as the visitors demand.
c. The construction of an open contemporary amphitheater is also proposed by the local authorities.

d. The establishment of a Post Graduate Course in Delphi, related to the Hellenic Civilization, is a proposal not only of the local authorities, but also of many international academicians.
e. Pikionis' pavilion should be much more promoted.

The development proposals for Delphi must contribute to the following:

- To bring out the cultural history and especially the archeological site.
- To bring out the natural environment.
- The protection and emergence of open and green space.
- The planning of land uses and local activities, which can lead to the development of local economy.
- The satisfaction of the visitors.

The key to the problem is to pay attention to the contradiction between antiquities protection and antiquities access. In particular:

- New main road that will be planned on the perimeter of the city and the antiquities, and will not pass through them, but as adjacent as possible, in order not to isolate Delphi from visitors!
- Secondary road for access to the antiquities and the museum.
- Urgent response to the parking problem of both cars and tourist buses both for the area of the antiquities and for the area outside the city.
- Development of a pedestrian network from the city to the antiquities and vice versa.
- Electric vehicles for visitor's transport.
- Urgent resolution of environmental problems:
  (1) waste management,
  (2) landslides in specific areas,
  (3) soil erosion,
  (4) use of renewable energy sources, both photovoltaics and wind turbines (of course out of sight of the settlement and the antiquities) since the orientation and the wind and solar potential of the surrounding area guarantee excellent results.

Measures for the future:

(1) continuous supervision of the implementation of the building regulation adapted to the special conditions of the area (shape, height, slope of the plots).
(2) measures for the problem of traffic and parking of both small and large vehicles.
(3) new Master Plan for the Delphi area which will both prevent the growth of already existing problems and propose effective solutions for the sustainable development of Delphi.

At the eastern entrance of the town, a new square has to be designed at an already existing unexploited space. Many functions of the settlement already take place close to this area:

- Commercial activities: the junction of the two central shopping streets are at the area.
- Administrative facilities of the local authorizes, located near the City Hall, the Cultural Center and the building of OTE (Greek Telecommunications Authority).
- A path that connects the town with the archeological sites.
- Cultural functions: an ideal point of view of the Delphic landscape and a traditional history point e.g. fountain "Tzaferi", the old mill etc.

Disabled accessibility

An important factor of the design is the safety and accessibility of disabled people. The visit and accommodation of people with disabilities should be facilitated at the museum, the archeological areas, for the access to them and in the open spaces. Also, all of the required services should be provided. The installation of specific signaling and marking, the special configuration of the parking are some of the legislation requirements, in order to facilitate the movement of persons with disabilities. The relevant requirements include special measures such as emitting beeps devices, swipe points on public spaces and more.

Pedestrian network

The design of pedestrian networks aims at the integration between the existing and new open spaces, the central parts of the town, the archeological areas, the museum and the natural sights. The route design of the pedestrian networks aims to facilitate the visit of the archeological and historical monuments, to enjoy the natural environmental beauty and to boost the local commercial activities. Benches, planting, water elements, informational signs which highlight the cultural continuity of tradition and modern history will enhance the using of pedestrian networks.

Restoration of traditional buildings facades

Aiming at the sustainable development of Delphi, a restoration of some selected traditional buildings or even the improving of newer buildings facades are suggested. Specifically, repair and color restoration of the buildings facades are recommended.

Parking facilities

The creation of at least two new larger parking places is urgently needed, just at the outskirts of the town, before the entrance, and immediately after the town.

Urban equipment

The urban equipment in the open spaces of Delphi will have to be replaced and increased. More benches, trash bins, shadow systems, billboards for local information have to be placed in the central roads, at the square, the parking and at walk sides. This equipment ensures comfort conditions to the pedestrians and visitors and informs them about the historical and cultural monuments and natural environmental sights. So, it contributes to the sustainable development of the town and the great sightseeing tour along the archeological areas and the contemporary cultural heritage monuments. The materials and the urban equipment have to be both harmonized with the aesthetics and architecture of the town's landscape. Also, disabled accessibility has to be taken under consideration. It is important for residents and visitors not to intermix the use of limited pedestrian and walk side areas, with cars' traffic and parking.

Open spaces

The design of open spaces may revitalize the town, increase the social interaction between the residents, improve the microclimate conditions, the thermal comfort conditions and the aesthetic environment. The upgrading of the existing open space and the environmental design of new areas in Delphi aims at the holistic approach of the archaeological sites, the settlement itself and the natural environment sightseeing.

Proposed visitors' paths

The walk sides around the archeological area, cultural monuments, natural sightseeing and town of Delphi will attract the interest of the visitors to spend more time in the area and to learn more about the historical heritage. It also benefits the local society and the commercial activities. An extended tourist season may create the optimum conditions for sustainable and economic development.

The walk sides must be free of obstacles, distinct by labels on pedestrian crossings.

Trees, vegetation, shadowing systems in resting and information points, benches and faucet for water will have to be incorporated in the upgrading. Night lighting should ensure the safety and the accessibility during afternoon time and bicycle lanes should be designed.

- The existing sidewalks could be maintained and extended in order to facilitate visitors. The routing can include:the path from archeological area to the town, which is located at the north side of the town and ends to the "Sikelianos" museum.
- the walkways that will connect the proposed parking spaces.
- a tour by vehicles/electric cars from the pavilion "Pikioni", the European Cultural Center of Delphi (EPKED), the olive grove, the settlement of Chrisso, and the ancient walls of Krissa.
- the ancient path: Kirra - Chrisso – Delphi.
- the international European path E4: Delphi - Agoriani (Eptalofos).
- the path: Delphi - Avgo - Corycian Cave.
- the path: Delphi - Pleistos river - Desfina.

The intersection of routes will be in the commercial center of the town, in order to boost the local society.

Maintenance and enhancement of Pikioni's pavilion

The preservation, repair, and maintenance of the building are of urgent importance and will contribute to the redevelopment of the pavilion as an exceptional entertainment site, just like it has been previously done with the restoration of Sikelianos house (1991) and its current use as a museum.

Cultural activities

The local population deals with a range of cultural and commercial activities. A proposed cultural and information center will shelter the local agencies and will offer information to the visitors about the history, the culture, the local society and the local commercial products. It is also hoped that the much-needed upgrading of the European Cultural Center of Delphi (EPKED) will be used to promote the conference tourism and thus new job offers and activities will be created.

Notice: All of the proposed measures, are based on today's existing environmental, planning, and archaeological legal framework, so that they might actually be implemented.

4 Conclusions

Except for summer, Christmas and Easter, during the other months of the year, Delphi seems to be neglected, therefore, the exceptional place of Delphi has to be more promoted and supported by tourist policy makers.
The aim of this study has been the investigation of the present situation in Delphi and the proposal of ideas for a sustainable development. The parameters and the conditions to achieve this goal are the development of the area, the comfort of the residents and visitors, the protection and emergence of the natural environment and of course the protection of and the accessibility to the archeological areas.

Acknowledgments

Many thanks to the members of K-ecoprojects, with my best wishes.

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Optimal site selection of electric vehicle charging stations exploiting multi-criteria decision analysis: The case of Greek municipalities

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Abstract. The opportunities created in the Greek electric vehicle (EV) market have allowed potential investors to participate in developing the country's EV charging infrastructure. Yet, the decision process of relevant stakeholders for strategic investments is challenging, involving the identification of the most promising charging sites from a set of multiple alternative locations of various features that may significantly affect their business competitive advantage. This paper attempts to facilitate decision-making in such settings using a comprehensive, yet thorough multi-criteria decision analysis framework. The proposed approach is validated by considering ten Greek municipalities of different characteristics. The results showcase the overall strengths of the proposed approach and its utility in the strategic planning process of potential investors.

Keywords: Electric Vehicles, Charging Stations, Multi-criteria Decision Analysis, PROMETHEE.

1 Introduction

The entry of battery electric vehicles (BEVs) in the Greek market is quite recent, with the first models appearing only in the last few years [1]. Most car manufacturers have been promoting the use of BEVs, but the response from Greek drivers has been relatively slow. This is in contrast to plug-in hybrid electric vehicles (PHEVs) that have become particularly popular in Greece. Lack of information about the benefits of electric vehicle (EV) mobility, high purchase cost, limited driving autonomy, and lack of public charging infrastructures are just some of the factors contributing to this phenomenon [2].

From the aforementioned factors, the development of an adequate public charging network is imperative for the promotion of EV mobility [3, 4] and the improvement of air quality in residential areas [5]. This is particularly true in Greece where a large proportion of drivers do not have access to private parking, especially in large urban areas. The municipal authorities are expected to play an active role in the correct and orderly development of such infrastructures based on the local geographical specifications, the residential needs, and the required layout and capacity of EV charging stations (EVCSs). With government funding, Greek municipalities have been conducting extensive research to identify the most suitable locations for placing EVCSs. The model for developing the charging network has not been decided yet, but the most prevalent seems to be that of the auction, i.e. assigning the deployment of EVCSs to private entities in exchange for a price.

The opportunities created by this situation in the field of EV mobility enable investors to actively participate in the national map of EVCSs in Greece. Choosing between municipalities for the installation of EVCSs is important for investors because it allows them to prioritize their investment decisions based on the potential return on investment in each location. While it is true that EVs will likely appear in many cities in Greece and investors can diversify the location of their stations, it is still crucial to identify the most promising ones to ensure the highest possible utilization rates and profitability. However, the strategic investment decision process involves identifying, evaluating, and choosing among numerous alternative projects that, depending on their features (e.g. construction and maintenance cost, recovery period, and accessibility), may have a major impact on the realized business competitive advantage of the investors. Therefore, selecting the most promising municipality for the installation of EVCSs becomes an important, multi-dimensional problem that most potential investors will ultimately have to face.

In this paper we present a methodological framework for comprehensively selecting the optimal site to install future EVCSs, taking into consideration four categories of factors that influence the final investment decision: economic, environmental, social, and technological factors. Due to the multi-dimensional nature of the problem, the proposed approach builds on a multi-criteria decision analysis (MCDA) method that effectively filters the alternatives and identifies the optimal solution such that no other feasible option exists that is equally good to the selected solution [6]. Apart from considering trade-offs among the various criteria defined, the proposed approach can also incorporate the judgment of decision makers (DMs), experts, and stakeholders (estimation of criteria weights), while also accounting for uncertainty (evaluation of criteria using qualitative measures) [7].

The rest of the paper is structured as follows: Section 2 includes a presentation of past studies on the problem of optimal EVCS placement. Section 3 presents the proposed methodological approach, including the criteria and MCDA method used, while Section 4 illustrates and discusses the results of an experimental application conducted in Greece. Finally, Section 5 concludes the paper and suggests areas for future research.

2 Literature review

Over the last decade, many studies have been conducted to solve the problem of EVCS optimal siting. The problem is naturally influenced by various conflicting factors, rendering it a multiple-criteria evaluation problem. Consequently, the success of its solution mainly depends on the MCDA method used, the criteria defined, and the weights assumed, all directly affecting the evaluation of the examined EVCS locations (alternatives to the problem). Table 1 presents a collection of such recent studies.

In [8], an MCDA method is developed through Linguistic Entropy Weight (LEW) and Fuzzy Axiomatic Design (FAD) to select a suitable location for an EVCS. Based on the opinions of experts from different fields, a literature survey, and an on-site survey, an evaluation system is designed for EVCS site selection with a sustainable perspective. The system includes 5 criteria about technology, economy, society, environment, and resources and 13 sub-criteria. The weights of the criteria are determined by the LEW method and the most suitable position of the EVCS is determined using the FAD. Furthermore, a comprehensive LEW-FAD analysis framework is constructed and the procedure for determining the optimal EVCS location is given. To assess the stability and robustness of the proposed method, sensitivity and comparison analyses are conducted. The results of the sensitivity analysis show that the ranking of the alternatives is not affected by changes in the functional requirements of the criteria, but is significantly affected by changes in the weights of the criteria. The advantages of the proposed method are highlighted in terms of stability and reliability by comparing it with three MCDA methods (TOPSIS, VIKOR, and MULTIMOORA) applied in previous studies. The results show that the application of the LEW-FAD analysis framework in EVCS location selection is robust, making it suitable for other developing or emerging economies.

The location selection of EVCS is extremely important regarding harmonious and sustainable development. However, errors in the use of multi-criteria decision-making methods could lead to inaccurate and irrational results. In [9], the PROMETHEE method is proposed in combination with the Cloud model to solve the problem of optimal location selection of an EVCS. Using the PROMETHEE method enhances confidence and visibility for DMs and the Cloud model is recommended to fully and accurately describe the randomness of linguistic terms. Finally, an Analytical Network Process (ANP) method is adopted to measure the correlation of indicators with a highly simplified calculation of the parameters and the required steps. The authors conclude that the proposed framework can compensate for many imperfections and inadequacies of traditional MCDA methods proposed in the literature.

Anthopoulos & Kolovou [10] introduced an MCDA framework for the development and operation of EV charging infrastructures in Greece. The Analytical Hierarchy Process (AHP) was the proposed method and the alternative actions were evaluated based on economical, technical, social, environmental, and policy criteria using 13 sub-criteria. The relative importance of each criterion was weighted based on a structured questionnaire given to the participating companies active in the charging infrastructure market in Greece. The results showed that the installation and operation of publicly accessible charging stations located in private spaces, exploited by private entities that can ensure their protection from vandalism, was the preferred action. Based on the criteria weights, it was concluded that with the current condition in Greece, the main incentives for charging operators are not the economic prospects of their investments, but mainly developmental and environmental ones. The selection of a viable installation site plays an important role in the life cycle of an EVCS, which must consider some conflicting criteria.

Guo & Zhao [11] used the Fuzzy TOPSIS method to find the optimal placement area. Based on the literature, research reports, and expert opinions in various fields, the evaluation system for EVCS site selection was built from a sustainability perspective, which consists of environmental, economic, and social criteria, as well as 11 related sub-criteria. Afterwards, the weight of each criterion was selected by five expert groups in the fields of environment, economy, society, electricity, and transport systems. Finally, the alternative EVCS area solutions were ranked using the Fuzzy TOPSIS method, and a sensitivity analysis was performed. The results of the sensitivity analysis showed that the original ideal alternative always secures its top ranking, no matter how the sub-criteria weights change. Moreover, environmental and social criteria required more attention from DMs than economic criteria.

Skaloumpakas et al. [12] also iteratively used the TOPSIS method to dynamically evaluate the alternative locations for the EVCS placement, considering a set of practical criteria related to the traffic intensity and the relative location of the charging stations with interchanges, major cities, and existing stations. The optimal locations were determined by taking into consideration constraints about the EV driving range and installation preferences and were showcased in the Egnatia Motorway, the longest highway in Greece.

Considering the shortcomings of previous heuristic optimization models in dealing with subjective factors, the GRA-VIKOR method was used in [13] to address the issue of EVCS placement. Economical, societal, environmental, and technological criteria were used and further sub-criteria were specified using the fuzzy Delphi method (FDM). In addition, to incorporate subjective opinions as well as objective information, expert ratings, and the Shannon entropy method were used to determine the weights. Next, the applicability of the proposed framework was demonstrated by an empirical study of five alternative EVCS locations in Tianjin. Environment-related sub-criteria received much more attention than other sub-criteria and the sensitivity analysis showed that the selection results remained stable no matter how the sub-criteria weights changed, which verifies the robustness and effectiveness of the proposed model and evaluation results. This study provides a comprehensive and efficient method for optimal placement of EVCS and also innovates in the weight determination and the distance calculation of the conventional fuzzy VIKOR.

In [14], an integrated EVCS site selection decision framework was built for residential communities (EVCSRC) in Beijing with triangular intuitive fuzzy numbers (TIFNs). First, the distinctive index system of EVCSRC site selection factors was established, including economy, society, environment, planning, and a characteristic portrait of residential communities. TIFNs were then used in place of DMs to express unspecified information. In addition, the Fuzzy-VIKOR method was used to rank the alternative EVCSRC positions. Finally, the case of Beijing was studied to demonstrate the validity of the proposed site selection framework. The result showed that the EVCSRC site located in the Haidian District of the Sijiqing Community should be selected as the optimal site and presented a feasible and easy-to-use decision-making framework for investors.

Table 1. Studies on optimal placement of EVCSs.

Title	Method	Reference
A multi-criteria approach for optimizing the placement of electric vehicle charging stations on highways	Dynamic TOPSIS	Skaloumpakas et al. (2022) [12]
A novel multi-criteria decision-making method for selecting the site of an electric-vehicle charging station from a sustainable perspective.	LEW & FAD	Feng et al. (2021) [8]
A Multi-Criteria Decision Process for EV Charging Stations' Deployment: Findings from Greece.	AHP	Anthopoulos & Kolovou (2021) [10]
A decision framework for electric vehicle charging station site selection for residential communities under an intuitionistic fuzzy environment: A case of Beijing.	Fuzzy VIKOR	Wu et al. (2017) [14]
Optimal siting of charging stations for electric vehicles based on fuzzy Delphi and hybrid multi-criteria decision-making approaches from an extended sustainability perspective.	GRA-VIKOR	Zhao & Li (2016) [13]
Optimal site selection of electric vehicle charging stations based on a cloud model and the PROMETHEE method.	PROMETHEE	Wu et al. (2016) [9]
Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective.	Fuzzy TOPSIS	Guo & Zhao (2015) [11]

Following the best practices identified in the literature, the present paper utilizes the PROMETHEE method and incorporates the most common, yet representative criteria of past studies, being based on four pillars: environment, economy, society, and technology. The contribution of the paper is found in the examination of a multi-complex ecosystem that includes islands, urban, and rural municipalities. To the best of our knowledge, this is the first paper that compares different geographical areas for the optimal site selection of EVCSs.

3 Multi-criteria decision analysis approach

3.1 General discussion

To assist DMs select the most promising municipality for placing a new EVCS, the proposed approach utilizes an MCDA method, a set of environmental, economical, social, and technical criteria identified in the literature, and the preferences of DMs to properly weigh each criterion. Consequently, the alternatives are evaluated and ranked, determining the municipalities of the highest potential. An overview of this proposed approach is presented in Figure 1.

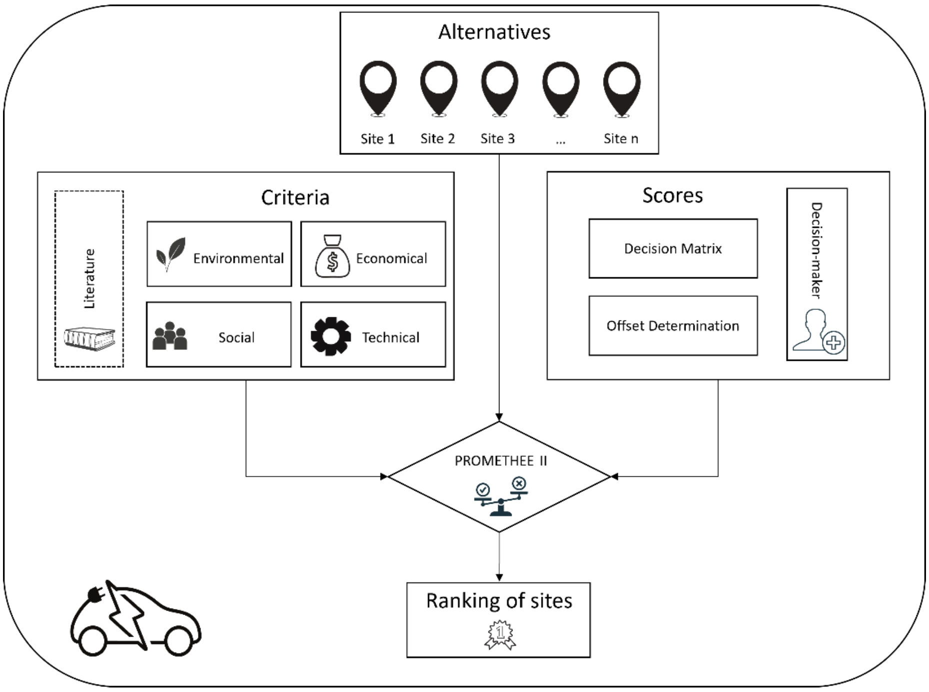

Fig. 1. Overview of the proposed MCDA approach

The MCDA considers seven sub-criteria {g1, g2, g3, g4, g5, g6, g7}, four of which have a positive impact {g1, g2, g6, g7}, while three a negative impact {g3, g4, g5}, as follows:

- **g1**: System safety, reflecting how the distance of the EVCS from the sea can impact the lifetime of the installation.
- **g2**: System reliability, indicating the frequency of power distribution network failures that impact the operation and lifetime of the EVCS.
- **g3**: Total construction cost, including different types of capital costs for constructing the EVCS.
- **g4**: Operation and maintenance cost, consisting of the costs for operating and

maintaining the EVCS.

- **g5**: Investment recovery period, indicating the payback period of the investment.
- **g6**: Accessibility, suggesting how easy it is to access the EVCS in terms of traffic congestion.
- **g7**: Air quality index, demonstrating the expected atmospheric pollution reduction that an EVCS can result in.

The seven sub-criteria are organized into four main criteria, as displayed in Figure 2.

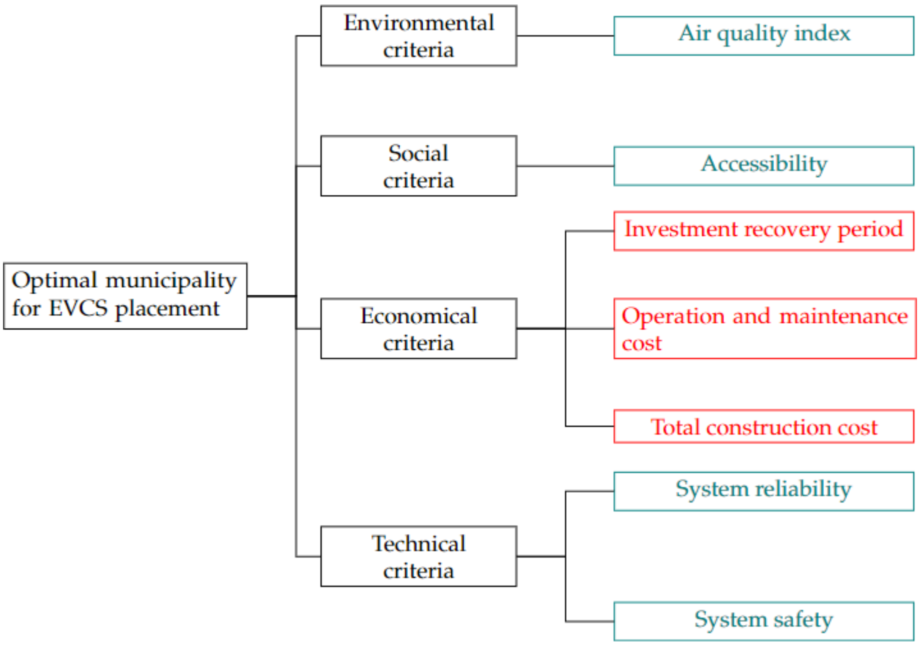

Fig. 2. Overview of the criteria and sub-criteria used in the proposed MCDA approach. Sub-criteria of a positive impact are denoted by green colour, while sub-criteria of a negative impact are denoted by red colour.

3.2 The PROMETHEE II method

The PROMETHEE I and PROMETHEE II (Preference Ranking Organization METHod for Enrichment of Evaluations) MCDA methods, introduced in [15], have been extensively applied to support decisions in businesses, healthcare, and education. PROMETHEE I provides a partial ranking of the actions, as it is based on the positive and negative flows of the criteria, including preferences, indifferences, and incomparabilities. On the contrary, PROMETHEE II provides a complete ranking of the actions, as it is based on the multi-criteria net flow. It includes a preference and indifference threshold, which will be explained in the following paragraphs. The steps followed by the PROMETHEE II method, as presented by Sarmas et al. [16]; Xidonas et al. [17], are the following:

- Firstly, pairwise comparisons are made between all the alternatives for each criterion:

$$d_k(a_i, a_j) = f_k(a_i) - f_k(a_j), \tag{1}$$

where $d_k(a_i, a_j)$ is the difference between the evaluations of alternatives a_i and a_j for criterion f_k, with i,j being the alternatives indices and k being the criterion index.

- These differences are translated to preference degrees, according to the selected criterion, as follows:

$$\pi_\kappa(\alpha_i, a_j) = P_k[d_k(a_i, a_j)], \tag{2}$$

where P_k: $R \rightarrow [0, 1]$ is a positive non-decreasing preference function, such that $P_j(0) = 0$.

- The pairwise comparison of the alternatives is completed by computing the multi-criteria preference degree of each pair, as follows:

$$\pi(a_i, a_j) = \sum_{i=1}^{q} \pi_\kappa(a_i, a_j) \times w_k, \tag{3}$$

where w_k represents the weight of criterion f_k, assuming that $w_k \geq 0$and $w_k = 1$.

- The positive (ϕ^+) and negative (ϕ^-) outranking flows are defined. The positive outranking flow expresses how an alternative is outranking the others. A higher positive outranking flow implies a better alternative.

$$\phi^+(\alpha) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x), \tag{4}$$

The negative outranking flow expresses how an alternative is outranked by all theothers. A lower positive outranking flow implies a better alternative.

$$\phi^-(\alpha) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x), \tag{5}$$

The positive and negative outranking flows are aggregated into the net preference flow:

$$\phi(\alpha) = \phi^+(\alpha) - \phi^-(\alpha), \tag{6}$$

The PROMETHEE II final ranking is obtained by ordering the alternatives accordingto the decreasing values of the net flows.

PROMETHEE II preference functions In PROMETHEE II, the preference functions are used to assess the relative preference of two alternatives $\{a_i, a_j\}$, based on their evaluation of different criteria. The difference between the evaluations of a_i and a_j on a particular criterion is denoted by d_k. Two thresholds are defined to use the preference functions: the indifference threshold (q_k) and the preference threshold (p_k). These thresholds are used to determine whether the difference between the evaluations of a_i and a_j on a particular criterion is negligible, significant, or somewhere in between. If the difference (d_k) is smaller than the indifference threshold (q_k), it is considered negligible, and the preference degree between the two alternatives on that criterion is set to zero. In other words, there is no preference for one alternative over the other if the difference between their evaluations is negligible. On the other hand, if the difference (d_k) is larger than the preference threshold (p_k), it is considered significant, and the preference degree is set to one. This means that there is a clear preference for one alternative over the other if the difference between their evaluations is significant. Finally, if the difference (d_k) is between the indifference threshold (q_k) and the preference threshold (p_k), the preference degree is calculated using a linear interpolation between zero and one. This allows for a gradual increase or decrease in the preference degree between the two alternatives as the difference between their evaluations on a particular criterion changes from negligible to significant.

For the criteria of the examined MCDA problem, the usual preference function is used as it is the simplest to implement, and also not depending on thresholds that may be challenging to define. The usual preference function is summarized as follows:

- If the difference d_k between the alternatives is zero, then the preference degree becomes equal to zero.
- If the difference d_k between the alternatives is greater than zero, then the preference degreebecomes equal to one.

3.3 Weighting system

Simos [18, 19] proposed a technique that allows DMs to practically express how they wish to prioritize a set of criteria in a given MCDA problem. This procedure aims to communicate to the analyst the information needed to attribute a numerical value to each criterion when used in ranking-type MCDA methods. The Simos method was later revised by Figueira and Roy [20] to address certain robustness issues of the original method. Their method is summarized below.

The DM is given a set of n cards displaying the name of the examined criteria. The DM uses the cards to rank the criteria from the least to the most important by arranging them in ascending order. If some criteria have the same importance for the DM, he/she can place them together in the same position. The importance of two successive criteria (or two successive subsets of ex aequo criteria in case two or more cards have been placed together) in the ranking can be more or less close. To depict this smaller or larger difference in the importance of successive criteria, the DM introduces white cards between two successive cards. The more the number of white cards between two successive criteria, the greater the difference between their importance. If no white card is placed between two successive ranks, then the difference between the weights of the criteria in these two successive ranks is set equal to the unit u used for measuring the intervals between weights. Hence, if one white card is placed between two successive ranks, then there is a difference of 2u between the weights of the criteria in these two successive ranks. Finally, the DM should state how many times the last criterion is more important than the first one. This ratio is denoted by the parameter z.

4 Experimental application

4.1 Alternatives

The proposed approach will be used to evaluate 10 municipalities of Greece and, subsequently, identify the most promising for placing an EVCS. The alternatives are shown in Figure 3 and consist of 4 municipalities located in Attica (Argyroupoli, Cholaros, Galatsi, and Kaisariani), 2 island municipalities (Chios and Kythera), and 4 province municipalities (Karpenissi, Lamia, Loutraki, and Pilos). These alternatives were selected because they sufficiently represent the geographic, demographic, and economic variations of Greek municipalities and have already attracted the interest of some investors in the Greek EV market.

Fig. 3. Location of the examined municipalities, classified based on their geographical position.

4.2 Sub-criteria description and evaluation

This subsection provides details on the seven sub-criteria considered for ranking the alternatives of the examined MCDA problem.

- **g1**: This sub-criterion reflects the extent the distance of the EVCS from the sea is expected to affect the lifetime of the installation (damage due to salt and moisture). A scale from 1 to 3 is used to rank the safety of the alternatives, where higher values indicate greater distance from the sea and, therefore, longer life expectancy for the installation. Specifically, municipalities located up to 2km from the sea receive a rating of 1, municipalities located up to 4km from the sea receive a rating of 2, while municipalities located farther than 4km from the sea receive a rating of 3 (see Table 2).

Table 2. Evaluation values of the alternatives in terms of safety (sub-criterion g1).

Distance from the sea	Scale
≤ 2km	1
2 – 4km	2
> 4km	3

- **g2**: This sub-criterion indicates the general reliability of the electric power distribution network, i.e. how likely it is for charging to be conducted without unexpected interruptions or disturbances that may damage the installation. A scale of 1 to 2 is used to evaluate the alternatives, where higher values indicate a more reliable power supply. The installations on the islands receive a lower rating than the installations on the mainland due to the more frequent outages and disruptions observed in the distribution network of the former. Therefore, island municipalities receive a rating of 1, while the rest of the municipalities a rating of 2 (see Table 3).

Table 3. Evaluation values of the alternatives in terms of reliability (sub-criterion g2).

Location of municipality	Scale
Island	1
Other	2

- **g3**: This sub-criterion illustrates the total construction cost of an EVCS which includes the cost of leasing or acquiring land, the cost of research and design, the cost of building the infrastructure, the cost of purchasing the required equipment and tools, the cost of construction management and production, and other capital costs of the project. To evaluate and rank each municipality based on this sub-criterion, the expertise of a research associate from one of the largest charging point operation companies in Greece was utilized. The associate possesses knowledge regarding the total construction cost required for installing a charging station in each of the municipalities under examination. A scale of 1 to 3 is used for evaluating the total construction cost at each municipality, where higher values imply higher costs (see Table 4).

Table 4. Evaluation values of the alternatives in terms of total construction cost (sub-criterion g3)

Total construction cost	Scale
Low	1
Average	2
High	3

- **g4**: This sub-criterion reflects the cost of operation and maintenance. Similar to g3, a scale of 1 to 3 is used for evaluation. In particular, due to the lack of specialized technical staff in islands and the province of Greece, the maintenance costs for municipalities outside Attica are typically higher. To that end, municipalities located on islands receive a rating of 3, municipalities located in Attica receive a rating of 1, while province municipalities a rating of 2 (see Table 5).

Table 5. Evaluation values of the alternatives in terms of operation and maintenance cost (sub-criterion g4).

Location of municipality	Scale
Attica	1
Province	2
Island	3

- **g5**: This sub-criterion pertains to the recovery period of investment, which is primarily determined by the anticipated number of EVs that will utilize the EVCSs. A higher volume of EVs is expected to result in increased usage of the EVCS, thus reducing the payback period and subsequently lowering the investment risk. The expected number of EVs is calculated based on the number of internal combustion engine cars that have been recorded in each municipality. However, it does not consider the seasonality of EV usage on an island due to tourism, as there is no clear way to measure it. According to the Greek Statistical Authority, more cars have been recorded moving in the region of Attica, fewer in the province, and significantly fewer on the islands. For this reason, municipalities located on islands receive a rating of 3, municipalities located in Attica receive a rating of 1, while municipalities in other locations receive a rating of 2 or 3, as there are provinces that have recorded similar car usage to municipalities located in islands (see Table 6).

Table 62. Evaluation values of the alternatives in terms of the investment recovery period (sub-criterion g5).

Location of municipality	Scale
Attica	1
Province	2 or 3
Island	3

- **g6**: To attract more customers, EVCSs must be easily accessible and located in areas with as little traffic congestion as possible. In the province and islands, traffic congestion is limited, even in the summer months. In contrast, municipalities of Attica typically experience high traffic congestion. As a result, municipalities located on islands receive a rating of 3, municipalities located in the province receive a rating of 2, while municipalities located in Attica receive a rating of 1 or 2, depending on their traffic congestion (see Table 7).

Table 73. Evaluation values of the alternatives in terms of accessibility (sub-criterion g6).

Location of municipality	Scale
Attica	1 or 2
Province	2
Island	3

- **g7**: Reducing air pollution is one of the most important incentives to promote the use of EVs. A higher value on the scale of this sub-criterion implies a greater reduction in air pollution. In metropolitan areas, the concentration of internal combustion engine vehicles tends to be higher due to higher population density, more extensive infrastructure, and greater economic activity. As a result, emissions from these vehicles can accumulate and lead to increased air pollution levels. For this reason, the installation of EVCSs in municipalities of big cities can increase the adoption of EV usage and lead to a significant reduction in air pollution. Therefore, municipalities located on islands receive a rating of 1, municipalities located in cities receive a rating of 3, and municipalities located in the province receive a rating of 2 or 3, depending on their population (see Table 8).

Table 8. Evaluation values of the alternatives in terms of expected air pollution reduction (sub-criterion g7).

Location of municipality	Scale
Attica	3
Province	2 or 3
Island	1

4.3 Sub-criteria weights

To evaluate the importance of the examined sub-criteria, the opinion of a research associate who works at one of the largest charging point operation companies in Greece was considered. The specific expert possesses extensive expertise in the realm of EV charging infrastructure, as well as the Greek EV market, and has significant experience in the installation of EVCSs across various regions in Greece. Based on his opinion, we arrive at the schema presented in Figure 4, illustrating the revised SIMOS method. In the problem of optimal EVCS placement across different municipalities according to the expert, the investment recovery period (g5) is identified as the most critical factor of the decision-making process, while sub-criteria such as safety (g1) and accessibility (g6) have the least impact on the judgment of the DM. The computational steps of the SIMOS method and the final estimated weights are presented in Table 9. Overall, economic criteria account for about 46% of the alternatives' value, technical criteria for 27%, and environmental andsocial criteria for just 13% each.

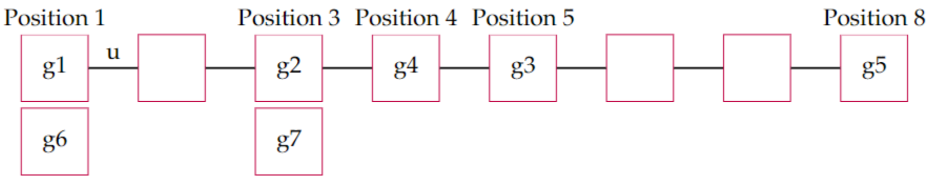

Fig. 7. Schema of cards during the application of the revised SIMOS method for the examined MCDA problem.

Table 9. Calculation of the normalised steps using the revised SIMOS method (z = 1.2).

Rank	**Subsets of ex aequo**	**Number of white cards between rank n, rank $n+1$**	**Non-normalised weights $k(r)$**	**Normalised weights k_i %**
1	g_1, g_6	1	1.00	12.95
2	g_2, g_7	0	1.08	13.99
3	g_4	0	1.12	14.51
4	g_3	2	1.16	15.03
5	g_5	...	1.28	16.58

4.4 Results and discussion

Based on the sub-criteria description and the expert's judgment, the evaluation of the alternatives across the sub-criteria is presented in Table 10. By utilizing the proposed EVCS placement approach, we identify the most promising municipality for the potential investors, as determined by the PROMETHEE II method, the defined sub-criteria, and the estimated sub-criteria weights. Table 11 shows the exact values of the calculated positive and negative outranking flows, as well as the net preference flow. Based on the latter, the final ranking of the municipalities is established.

As seen, the top-ranked alternatives (Argyroupoli, Galatsi, Kaisariani, and Cholargos) are the municipalities of Attica, while the bottom two alternatives (Kythera and Chios) are the municipalities of the examined islands. This finding can be attributed to the relatively higher evaluation values all city municipalities receive at key sub-criteria, such as g4 and g5. Therefore, we conclude that investing in EV charging infrastructures in islands is less promising than investing in cities. Yet, even within cities, different opportunities may be present depending on the particular characteristics of each municipality. For instance, Cholargos is significantly less promising than the rest of the Attica municipalities, mostly due to the higher total construction cost that was judged by the CPO and, simultaneously, its less accessible location.

To better showcase the differences between the PROMETHEE II rankings of the alternatives, two figures are rendered. In Figure 5, the vertical axis shows the overall ranking of the alternatives (the green colour indicates the positive outranking flow, while the red colour the negative outranking flow). The axes that create a 45°with the vertical axis, corresponding to the positive (left axis) and negative (right axis) flow values, are also provided to facilitate comparisons. In Figure 6, a node-based network is presented based on the ranking of the alternatives. The highest node is the top-ranked alternative (a. Argyroupoli) and the preferences are indicated by the arrows. The larger the difference between the net preference flows of each alternative (node), the bigger the distance between the nodes.

Table 10. Evaluation values of the alternatives based on the sub-criteria descriptions and the DM's knowledge. Values are presented for each criterion separately.

Alternative	g1	g2	g3	g4	g5	g6	g7
a.Argyroupoli	3	2	3	1	1	2	3
b.Galatsi	3	2	2	1	1	1	3
c.Kaisariani	3	2	2	1	1	1	3
d.Cholargos	3	2	3	1	1	1	3
e.Loutraki	2	2	2	2	2	2	3
f.Lamia	3	2	1	2	3	2	3
g.Karpenissi	3	2	1	2	3	2	2
h.Pilos	2	2	2	2	2	2	2
i.Kythera	1	1	1	3	3	3	1
j.Chios	1	1	1	3	3	3	1

Table 11. Ranking of the alternatives based on the PROMETHEE II net preference flow.

Alternative	ϕ^+	ϕ^-	ϕ	Ranking
a.Argyroupoli	0.4018	0.1638	0.2380	1
b.Galatsi	0.3921	0.1687	0.2234	2
c.Kaisariani	0.3921	0.1687	0.2234	2
d.Cholargos	0.3584	0.2361	0.1223	4
e.Loutraki	0.3263	0.2056	0.1208	5
f.Lamia	0.2961	0.2963	-0.0002	6
g.Karpenissi	0.3040	0.3229	-0.0189	7
h.Pilos	0.2737	0.4136	-0.1399	8
i.Kythera	0.2169	0.6013	-0.3844	9
j.Chios	0.2169	0.6013	-0.3844	9

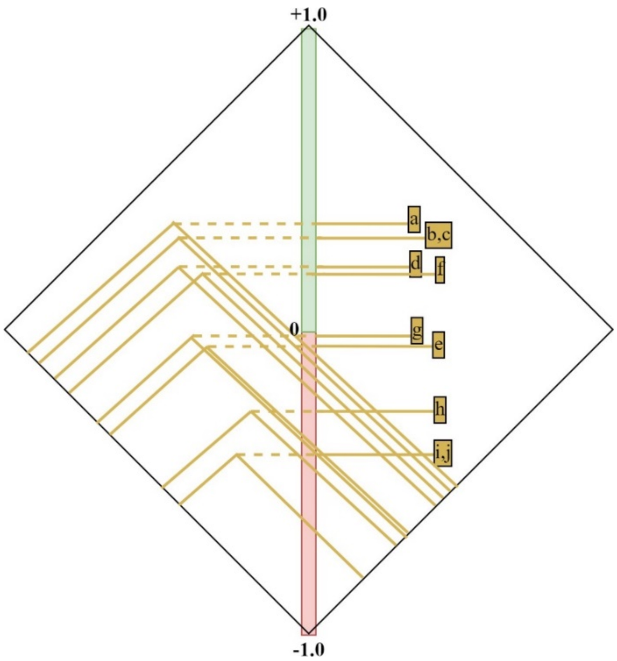

Fig. 5. The PROMETHEE II diamond illustrates the differences between the alternatives in terms of net preference, positive outranking flow, and negative outranking flow.

5 Conclusions

This study proposed a framework to support decisions related to the optimal placement of EVCSs in diverse municipalities to maximize profits and minimize the risks of potential investors. The proposed approach is based on the PROMETHEE II MCDA method and exploits a set of comprehensive criteria that cover critical aspects of said investments.

The utility of the proposed approach was validated using a set of ten municipalities in Greece. Our results indicate that municipalities located in large cities are preferable for investing and that island municipalities should be carefully assessed before deploying EVCSs. Yet, even within similar city municipalities, bigger opportunities can still be identified depending on the special characteristics of each alternative. Moreover, it is found that the most crucial criteria for assessing the examined investments are of an economic nature, consisting of the total construction cost, the operation and maintenance cost, and the investment recovery period. This conclusion is based on the expert's opinion, which in our case was the CPO. Technical, environmental and social criteria may have greater importance if other experts from their respective fields were to be included in the study.

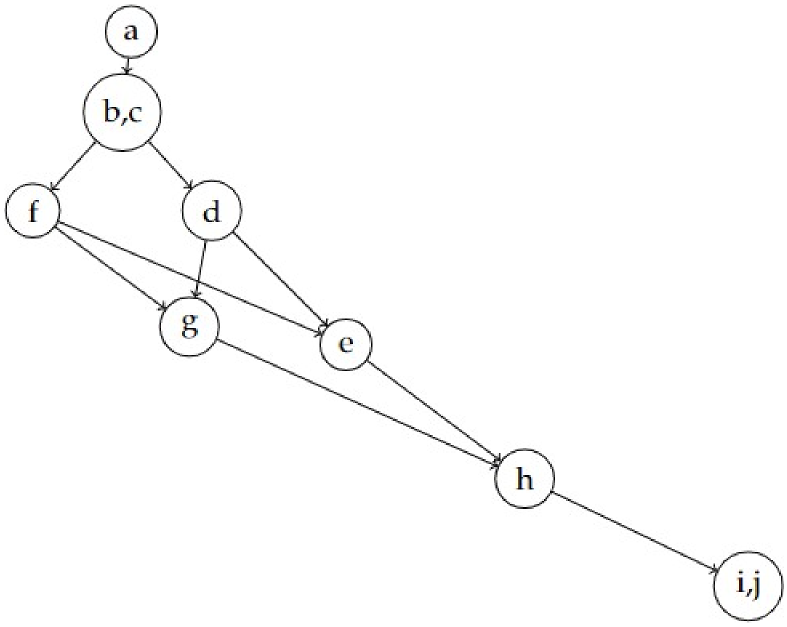

Fig. 6. Network based on the positive and negative outranking flows calculated by the PROMETHEE II method.

Future work in different directions could assist in improving some limitations of the present work. First, the criteria used could be expanded to reflect the competition (e.g. current number of EVCSs) in each municipality and the number of chargers that should be deployed per case based on the predicted demand to better estimate the costs and risks of the potential investors. In addition, when further data becomes available for each municipality, it would be recommended to take into account criteria related to the existing power network and the convenience of connecting the chargers to it. Second, the number of alternatives could be increased so that the analysis covers more locations and the results demonstrate the relative strengths and weaknesses of multiple municipalities. Third, the judgment of more experts that have significant experience in the EV market of Greece could be analysed, contributing towards the more accurate estimation of the criteria weights. Finally, the reported results, ranked from an investor perspective, could be compared to those computed from a social perspective to better understand how sustainable mobility could be reconciled with financial prosperity.

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